S
625.734
M41a
V.2

PLEASE RETU

APPLICATION HYDROLOGIC AND HYDRAULIC RESEARCH TO CULVERT SELECTION IN MONTANA

VOL II APPENDICES

Department of Civil Engineering & Engineering Mechanics Montana State University Bozeman

MST MAY 9 '79

MST APR 29 '81
[illegible]

AUG 2 9 1996

MONTANA STATE LIBRARY
S 625.734 M41a c.1 v.2 Dodge
Application hydrologic and hydraulic res
3 0864 00003986 0

PLEASE RETURN

STATE DOCUMENTS
MAR 7 197

APPLICATION HYDROLOGIC AND HYDRAULIC RESEARCH TO CULVERT SELECTION IN MONTANA

MONTANA STATE LIBRARY
930 East Lyndale Avenue
Helena, Montana 59601

VOL II APPENDICES

Vol I Report
Vol II Appendices

Prepared for

Planning and Research Bureau
Department of Highways
State of Montana
Helena, Montana

in cooperation with

U.S. Department of Transportation
Federal Highway Administration

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Montana Department of Highways or the Federal Highway Administration

Prepared by

Dr. E. R. Dodge
Professor of Civil Engineering

Montana State University
Department of Civil Engineering and Engineering Mechanics
Bozeman, Montana 59715

September 15, 1972

INDEX OF APPENDICES

See each Appendix for detailed Table of Contents

APPENDIX	TITLE
A	REGRESSION DATA
B	FLOOD PREDICTION DATA AND METHODS FOR NATURAL WATERSHEDS
C	CONFIDENCE INTERVALS
D	HYDRAULIC DESIGN TABLES AND CHARTS
E	CULVERT SELECTION PROCEDURES PERFORMANCE CHARTS AND DATA

Digitized by the Internet Archive
in 2015

https://archive.org/details/applicationhydr1972dodg_0

APPENDIX A

REGRESSION DATA

TABLE OF CONTENTS

Page

DATA FOR REGRESSION ANALYSIS AND REGIONAL FREQUENCY ANALYSIS 1

INDEX FOR REGRESSION PARAMETERS 3

PROGRAM FOR LISTING REGRESSION ANALYSIS DATA 4

REGRESSION ANALYSIS DATA

REGION I 6
REGION II 8
REGION III 10
REGION IV 12
REGION V 14
REGION VI 16
REGION VII 18
REGION VIII 20
REGION IX 24

DATA FOR REGRESSION ANALYSIS AND REGIONAL FREQUENCY ANALYSIS

The data which was used in the Regional Frequency Analysis Program is available on computer cards and is also stored on magtape. Both are on file in the Montana State University Department of Civil Engineering and Engineering Mechanics.

The data card arrangement for each station consists of a watershed information card, which contains the station number and information about the particular watershed, followed by cards containing the flood peaks and the years in which they occurred. The exact contents of a set of cards are as follows:

Card 1:	Watershed card station No., number of flood peaks in the record, drainage area (sq mi), mean basin elevation (ft) and mean channel slope (ft per mi)
Card 2,3, etc.	year-flood peak, year-flood peak, (Maximum 8 per card)

The estimated flood flows and watershed parameter data used in the Regression Analysis are tabulated here by Flood Regions, and are likewise available both on cards and magtape.

This data has been arranged so that five cards are required for each gaging station. The first card contain dependent variable flood values generated by the Regional Frequency Analysis program using a regional skew coefficient. These values were used in the Regression Analysis.

The second and third cards contain an alternate set of dependent variable values which were generated using the individual skew coefficients obtained from the Regional Frequency Analysis Program. These values were not used in the Regression Analysis.

The fourth and fifth cards contain values for the independent watershed parameter variables.

The specific arrangement of the variables on the cards is given below. Refer to the INDEX FOR REGRESSION PARAMETERS (next page) for the meaning of the variable names.

Card 1: Q-2, Q-5, Q-10, Q-25, Q-50, M-Log, S-DEV

Card 2: Q-10, Q_{10}/A, Q-25, Q_{25}/A, Q-50, Q_{50}/A, Q_{10}/Q_2, Q_{25}/Q_2, Q_{50}/Q_2

Card 3: M-LOG, S-DEV, Q-2,Q_2/A

Card 4: Area, Slope, C-LEN, %-LKS, ELEV, %-FR, PWB, % > 6000

Card 5: P-SCS, P-IN, S-INDX, Aspect, % > 3000

Note: Flood magnitudes for various recurrence intervals are designated as Q-i or Q_i. The meaning is the same.

The format for reading the 18 variables used in the regression analysis was as follows:

```
Format: (8X,5F8.0,2F8.3///8X,8F8.2/8X,3F8.2)
```

An INDEX FOR REGRESSION PARAMETERS containing descriptions of all 23 variables follows.

The data values for each of the 23 variables used in the Regression Analysis are listed on the following pages, following the Fortran IV program used for listing from the cards.

Table Col No	Symbol	Description of Variable	Units
1	Q-2	2-year flood	cfs
2	Q-5	5-year flood	cfs
3	Q-10	10-year flood	cfs
4	Q-25	25-year flood	cfs
5	Q-50	50-year flood	cfs
6	M-LOG	Mean of the $\log_{10}$ of all flood peaks at a station	
7	S-DEV	Standard deviation of $\log_{10}$ of all flood peaks at a station	
8	AREA	Drainage area	square mile
9	SLOPE	Main channel slope determined from elev at 15 and 85% of the distance along channel from gaging station to divide	feet/mile
10	C-LEN	Length of main channel	mile
11	%-LKS	Percent of area covered by lakes or ponds	%
12	ELEV	Average elevation of watershed	feet x 1000
13	%-FR	Percent of area covered by forest	%
14	P-WB*	Weather Bureau mean annual precipitation	inch
15	%>6//*	Percent of drainage area above 6000' elev	%
16	P-SCS*	Soil Conservation Service mean annual precipitation	inch
17	P-IN*	2-year 24 hour rainfall intensity	inch/24 hour
18	S-IDX*	Soil storage index	inch
19	L/R*S	Channel length ÷ the square root of the channel slope	mile
20	19/A67	19 ÷ drainage area raised to .67 power	mile/sq. $\text{mile}^{.67}$
21	15/18S	%>6000 ÷ soil index squared	$1/\text{inch}^2$
22	8/10S	Drainage Area ÷ channel length squared	sq. mile/sq. mile
23	16/18S	SCS mean annual precip ÷ soil index squared	$\text{inch}/\text{inch}^2$

*Abbreviated versions of these variable symbols appear in the Regression Analysis discussion of the report. The exact Fortran variable names used may also be slightly different.

Note: Values of variables Table Col 8-15 inclusive and Col 17 and 18 (if published) taken from A Proposed Stream Flow-Data Program for Montana, F.C. Boner and G.W. Buswell, 1970, Open File Report, U.S. Geological Survey, Helena, Montana

```
      DIMENSIØN X(40), STA(2,50), XNAME(2,40),NS(10), Y(50,30),TITL(40)
      READ (105,5) NBAT,(NS(I),I=1,NBAT)
    5 FØRMAT (12I5)
      WRITE(108,3)
      WRITE(108,5) NBAT,(NS(I),I=1,NBAT)
    3 FØRMAT(' NBAT   NS   NS   NS   NS.....',/)
      K=1;KW=0;NB=0
      READ(105,10) (XNAME(I,J),I=1,2),J=1,12
   10 FØRMAT(12(A4,A2))
      READ(105,11)(XNAME(I,J),I=1,2),J=13,24
   11 FØRMAT(8(A4,A2),4(A4,A3))
    4 END FILE 108
      READ(105,110) (TITL(I),I=1,10)
  110 FØRMAT(10A4)
      WRITE(108,111) (TITL(I),I=1,10)
  111 FØRMAT(//,50X,10A4,//)
      N = 1
      ØUTPUT '           CØLUMNS 1 = 7 ARE FLØØD FREQUENCY DATA
     1           CØLUMNS 8 = 12 ARE WATERSHED PARAMETERS'
      ØUTPUT ' '
      ØUTPUT '                1        2          3          4          5
     1     6      7       8       9    10      11      12'
      WRITE(108,51) (XNAME(I,J),I=1,2),J=1,13
   51 FØRMAT('CASE',5X,(A4,A2), 2(1X,(A4,A2)),         3(4X,(A4,A2)),1X,
     12(1X,(A4,A2)),3X,(A4,A2),1X,(A4,A2), (A4,A2),2(1X,(A4,A2))/)
   50 READ(105,20) (STA(I,N),I=1,2),(X(I),I=1,18)
   20 FØRMAT(2A4,5F8.0,2F8.3///8X,8F8.2/8X,3F8.2)
      X(19) = X(10)/SQRT(X(9))
      X(20) = X(19)/(X(8)**.67)
      X(21) = X(15)/(X(18)*X(18))
      X(22) = X(8)/( X(10)*X(10))
      X(23) = X(16)/(X(18)*X(18))
      WRITE(108,60) N,(STA(I,N),I=1,2),(X(I),I=1,12)
   60 FØRMAT(1X,I3,1X,2A4,F6.0,F7.0,1X,3F10.0,F9.3,F7.3,F8.1,F8.1,F6.1,
     11X,2F6.2)
      DØ 71 J = 13,24
   71 Y(N,J) = X(J)
      N=N+1
      IF(N=1.LT.NS(K)) GØ TØ 50
      END FILE 108
      WRITE(108,112) (TITL(I),I=1,10)
  112 FORMAT(//,50X,10A4,//)
      OUTPUT '                                         COLUMNS 13 = 23 ARE WAT
     1ERSHED PARAMETERS '
      OUTPUT  ' '
      OUTPUT '                  13        14      15          16         17
     118        19        20        21       22          23'
      WRITE(108,70) (XNAME(I,1),I=1,2),((XNAME(I,J),I=1,2),J=14,24)
   70 FORMAT('CASE',5X,(A4,A2),(A4,A2),2X,2(A4,A2),2(4X,A4,A2),6(2X,(
     1A4,A2))/)
      DO 81 L=1,NS(K)
      WRITE(108,82) L,(STA(I,L),I=1,2),(Y(L,J),J=13,23)
   82 FORMAT(1X,I3,1X,2A4,F6.1,F8.1,F7.1,F10.1,F9.2,F9.3,F8.2,F9.3,F8.3,
     1F7.3,F9.3)
   81 CONTINUE
      NB = NB + 1
      IF (NB.LT.NBAT) K=K+1;KW=0;GO TO 4
      CALL EXIT
      END
```

```
                                              REGRESSION DATA FOR REGION I

          COLUMNS 1 - 7 ARE FLOOD FREQUENCY DATA                                    COLUMNS 8 - 12 ARE WATERSHED PARAMETERS

                      1        2            3           4           5          6       7         8        9      10      11     12
CASE       STA       Q-2      Q-5         Q-10        Q-25        Q-50       M-LOG   S-DEV     AREA     SLOPE  C-LEN   %-LKS  ELEV

  1      5-100.   1324.    1704.         1917.       2151.       2305.      3.110    .142      74.8     42.1   14.2    3.23   6.18
  2      5-110.   1913.    2574.         2955.       3382.       3667.      3.268    .166     121.0     23.7   22.6    2.41   5.92
  3      5-115.   2189.    2624.         2850.       3084.       3230.      3.330    .104      61.0     74.7   11.7    1.82   6.06
  4      5-125.    519.     638.          702.        771.        816.      2.706    .115      21.0    190.0    7.0    3.38   5.61
  5      5-130.   4450.    5566.         6162.       6796.       7198.      3.635    .128     238.0     27.6   26.6    3.73   5.91
  6      5-140.    170.     224.          255.        289.        312.      2.216    .155       3.5   1560.0    2.3    6.48   6.53
  7      5-145.   1009.    1283.         1435.       1602.       1710.      2.993    .135      31.4    283.0    7.1    4.41   6.46
  8      6-730.   1124.    2032.         2678.       3509.       4126.      3.023    .333     123.0     33.7   21.8    1.00   6.28
  9      6-735.   1866.    3558.         5167.       7913.      10591.      3.297    .315     325.0     50.3   46.3    1.19   5.33
 10      6-785.   2928.    3595.         3983.       4427.       4732.      3.463    .109     258.0     48.5   27.4    1.05   6.15
 11      6-796.    130.     306.          462.        694.        889.      2.073    .473      20.3    153.0    6.5    1.00   6.05
 12      6-800.   6959.    8951.        10067.      11293.      12099.      3.831    .141     609.0     42.6   29.8    1.29   6.33
 13      6-925.   1479.    2235.         2774.       3492.       4052.      3.170    .213     133.0     66.0   28.2    1.66   6.02
 14      6-980.    431.    1144.         1909.       3299.       4701.      2.631    .501     137.0     67.3   27.8    1.59   5.04
 15      6-997.     60.     151.          248.        427.        611.      1.769    .476      20.2     65.1   11.1    1.00   4.59
 16     6-1060.    585.    1014.         1355.       1849.       2263.      2.766    .282     223.0    107.0   32.2    1.20   4.91
 17     6-1327.    923.    2723.         4734.       8459.      12247.      2.956    .556     325.0     29.6   45.1    1.31   5.00
 18     6-1330.    977.    2188.         3337.       5235.       7003.      2.989    .416     397.0     19.7   67.6    1.32   4.87
```

REGRESSION DATA FOR REGION I

COLUMNS 13 - 23 ARE WATERSHED PARAMETERS

CASE	STA	13 %-FR	14 P-WB	15 %>6//	16 P-SCS	17 P-IN	18 S-IDX	19 L/R*S	20 19/A67	21 15/18S	22 8/10S	23 16/18S
1	5-100.	52.3	51.0	59.0	83.0	2.10	3.200	2.19	.122	5.762	.371	8.105
2	5-110.	60.8	44.0	47.0	82.9	2.00	3.300	4.64	.187	4.316	.237	7.612
3	5-115.	54.9	49.0	57.0	83.9	2.00	3.200	1.35	.086	5.566	.446	8.193
4	5-125.	71.6	48.0	34.0	80.5	2.00	3.700	.51	.066	2.484	.429	5.880
5	5-130.	59.6	48.0	49.0	82.0	2.00	4.700	5.06	.129	2.218	.336	3.712
6	5-140.	48.4	56.0	73.0	107.2	2.10	4.300	.06	.025	3.948	.656	5.798
7	5-145.	59.1	55.0	65.0	100.6	2.10	4.500	.42	.042	3.210	.623	4.968
8	6-730.	92.3	16.0	77.0	34.2	2.00	4.100	3.76	.149	4.581	.259	2.035
9	6-735.	56.0	15.0	32.0	27.3	1.90	5.200	6.53	.135	1.183	.152	1.010
10	6-785.	88.8	25.0	62.0	40.6	2.00	5.600	3.93	.095	1.977	.344	1.295
11	6-796.	91.3	18.0	71.0	25.7	1.70	6.100	.53	.070	1.908	.480	.691
12	6-800.	86.5	22.0	71.0	38.9	2.00	6.100	4.57	.062	1.908	.686	1.045
13	6-925.	60.3	27.0	52.0	40.2	2.00	3.700	3.47	.131	3.798	.167	2.936
14	6-980.	28.5	15.0	17.0	24.2	1.80	4.300	3.39	.125	.919	.177	1.309
15	6-997.	6.9	14.0	1.0	18.5	1.70	4.300	1.38	.184	.054	.164	1.001
16	6-1060.	14.6	14.0	19.0	20.8	1.80	4.500	3.11	.083	.938	.215	1.027
17	6-1327.	20.4	18.0	6.0	24.6	1.60	5.200	8.29	.172	.222	.160	.910
18	6-1330.	15.8	17.0	6.0	21.9	1.60	5.200	15.23	.276	.222	.087	.810

REGRESSION DATA FOR REGION II

COLUMNS 1 - 7 ARE FLOOD FREQUENCY DATA

COLUMNS 8 - 12 ARE WATERSHED PARAMETERS

CASE	STA	1 Q-2	2 Q-5	3 Q-10	4 Q-25	5 Q-50	6 M-LOG	7 S-DEV	8 AREA	9 SLOPE	10 C-LEN	11 %-LKS	12 ELEV
1	6-303.	17.	45.	78.	144.	217.	1.263	.476	4.5	317.0	5.6	1.00	5.44
2	6-555.	362.	593.	788.	1091.	1364.	2.578	.240	78.0	219.0	14.9	1.00	6.98
3	6-562.	18.	28.	38.	52.	65.	1.261	.233	2.6	258.0	2.8	1.00	6.32
4	6-566.	240.	334.	421.	549.	658.	2.365	.193	87.7	131.0	14.2	1.00	6.17
5	6-587.	16.	51.	99.	215.	366.	1.248	.561	8.1	302.0	6.4	1.00	5.00
6	6-615.	209.	349.	470.	660.	832.	2.340	.251	192.0	157.0	20.8	1.10	5.66
7	6-619.	120.	207.	284.	409.	524.	2.099	.267	33.2	212.0	8.8	1.00	5.98
8	6-685.	119.	190.	249.	340.	420.	2.094	.228	44.0	255.0	6.2	1.00	5.90
9	6-712.	60.	149.	252.	460.	694.	1.812	.442	29.4	130.0	9.4	1.00	5.22
10	6-714.	58.	205.	427.	988.	1753.	1.798	.622	15.9	108.0	5.1	1.00	4.09
11	6-716.	131.	337.	583.	1088.	1670.	2.150	.456	35.0	133.0	13.5	1.00	4.65
12	6-745.	136.	294.	449.	714.	972.	2.146	.387	30.7	115.0	10.5	1.00	6.62
13	6-756.	11.	15.	18.	21.	24.	1.060	.151	6.0	152.0	6.6	1.00	5.99
14	6-760.	11.	23.	34.	53.	71.	1.043	.373	6.7	223.0	4.5	1.00	6.33
15	6-767.	53.	82.	104.	133.	157.	1.729	.220	5.3	150.0	4.9	1.00	7.20
16	6-768.	7.	11.	14.	17.	21.	.858	.214	1.5	590.0	2.6	1.00	7.19
17	6-770.	188.	272.	333.	416.	482.	2.280	.186	54.4	85.4	10.9	1.00	6.91
18	6-905.	1296.	2084.	2728.	3668.	4463.	3.112	.248	368.0	60.2	35.4	1.00	6.19
19	6-1021.	21.	77.	138.	247.	353.	1.324	.648	.8	140.0	1.9	1.00	2.77
20	6-1022.	19.	71.	137.	274.	426.	1.277	.676	1.6	150.0	2.9	1.00	2.83
21	6-1023.	7.	19.	31.	53.	75.	.843	.506	.2	189.0	1.1	1.00	2.75
22	6-1098.	206.	459.	697.	1090.	1457.	2.305	.413	58.7	126.0	12.7	1.10	6.64
23	6-1110.	391.	1257.	2142.	3579.	4843.	2.501	.671	337.0	40.6	32.8	1.04	4.64
24	6-1121.	253.	491.	661.	875.	1030.	2.357	.385	47.9	127.0	17.9	1.00	6.08
25	6-1155.	86.	157.	216.	302.	376.	1.934	.310	31.4	131.0	13.2	1.00	6.12
26	6-1185.	708.	1017.	1225.	1489.	1686.	2.846	.190	287.0	58.7	23.8	1.13	6.11
27	6-1206.	9.	25.	40.	64.	85.	.907	.566	.5	160.0	1.0	1.00	5.40
28	6-1207.	71.	146.	206.	287.	350.	1.811	.407	1.9	156.0	3.5	1.00	5.20
29	6-1208.	175.	548.	952.	1656.	2326.	2.194	.630	21.2	59.4	11.7	1.00	4.57
30	6-1209.	478.	966.	1353.	1893.	2324.	2.653	.387	88.7	69.3	27.8	1.00	4.93
31	6-1290.	1534.	3399.	4698.	6235.	7256.	3.101	.502	684.0	12.7	68.4	1.50	3.47
32	6-1930.	552.	814.	996.	1237.	1422.	2.742	.200	87.8	87.7	15.2	1.00	7.04
33	6-1970.	380.	960.	1559.	2613.	3648.	2.580	.478	74.9	304.0	13.1	1.41	6.68

REGRESSION DATA FOR REGION II

COLUMNS 13 - 23 ARE WATERSHED PARAMETERS

CASE	STA	13 %-FR	14 P-WB	15 %>6//	16 P-SCS	17 P-IN	18 S-IDX	19 L/R*S	20 19/A67	21 15/18S	22 8/10S	23 16/18S
1	6-303.	18.0	12.0	32.0	10.4	1.20	3.000	.31	.115	3.556	.143	1.156
2	6-555.	90.5	12.0	87.0	24.4	1.50	4.700	1.01	.054	3.938	.351	1.105
3	6-562.	1.0	13.0	86.0	23.0	1.40	3.300	.17	.092	7.897	.330	2.112
4	6-566.	76.0	13.0	62.0	23.7	1.40	3.300	1.24	.062	5.693	.435	2.176
5	6-587.	46.0	12.0	13.0	15.0	1.40	3.300	.37	.091	1.194	.198	1.377
6	6-615.	84.5	12.0	35.0	19.9	1.30	4.300	1.66	.049	1.893	.444	1.076
7	6-619.	97.0	12.0	48.0	20.6	1.50	3.900	.60	.058	3.156	.429	1.354
8	6-685.	98.1	12.0	56.0	25.0	1.40	4.900	.39	.031	2.332	1.145	1.041
9	6-712.	86.7	13.0	24.0	24.9	1.60	3.300	.82	.086	2.204	.333	2.286
10	6-714.	9.0	14.0	1.0	12.5	1.60	3.000	.49	.077	.111	.611	1.389
11	6-716.	70.0	13.0	3.0	18.0	1.70	2.500	1.17	.108	.480	.192	2.880
12	6-745.	81.4	22.0	84.0	25.3	1.60	4.300	.98	.099	4.543	.278	1.368
13	6-756.	34.0	18.0	57.0	18.5	1.40	2.500	.54	.161	9.120	.138	2.960
14	6-760.	98.0	23.0	80.0	25.0	1.40	4.900	.30	.084	3.332	.333	1.041
15	6-767.	100.0	25.0	100.0	30.0	2.00	5.100	.40	.131	3.845	.221	1.153
16	6-768.	94.0	24.0	100.0	29.0	1.70	4.500	.11	.082	4.938	.219	1.432
17	6-770.	96.5	24.0	95.0	28.3	1.90	4.500	1.18	.081	4.691	.458	1.398
18	6-905.	89.3	20.0	57.0	25.7	2.10	4.100	4.56	.087	3.391	.294	1.529
19	6-1021.	1.0	13.0	1.0	12.0	1.60	2.600	.16	.180	.148	.233	1.775
20	6-1022.	1.0	13.0	1.0	12.0	1.60	2.600	.24	.171	.148	.193	1.775
21	6-1023.	1.0	13.0	1.0	12.0	1.60	2.600	.08	.203	.148	.207	1.775
22	6-1098.	94.4	17.0	95.0	27.6	2.00	3.300	1.13	.074	8.724	.364	2.534
23	6-1110.	6.3	15.0	3.0	16.5	1.60	3.500	5.15	.104	.245	.313	1.347
24	6-1121.	63.0	16.0	50.0	29.7	2.20	2.800	1.59	.119	6.378	.149	3.788
25	6-1155.	53.4	17.0	78.0	22.7	1.70	3.500	1.15	.115	6.367	.180	1.853
26	6-1185.	47.6	14.0	61.0	20.3	1.70	3.200	3.11	.070	5.957	.507	1.982
27	6-1206.	1.0	15.0	1.0	15.5	1.60	5.400	.08	.131	.034	.470	.532
28	6-1207.	1.0	15.0	1.0	14.5	1.55	5.400	.28	.181	.034	.157	.497
29	6-1208.	1.0	14.0	1.0	13.6	1.40	3.000	1.52	.196	.111	.155	1.511
30	6-1209.	8.0	15.0	9.0	14.4	1.75	2.500	3.34	.165	1.440	.115	2.304
31	6-1290.	4.9	15.0	3.0	14.8	1.45	1.900	19.19	.242	.831	.146	4.100
32	6-1930.	84.5	13.0	98.0	27.5	1.90	4.700	1.62	.081	4.436	.380	1.245
33	6-1970.	43.9	13.0	60.0	29.0	2.20	3.900	.75	.042	3.945	.436	1.907

```
                                                      REGRESSION DATA FOR REGION III

            COLUMNS 1 - 7 ARE FLOOD FREQUENCY DATA                                  COLUMNS 8 - 12 ARE WATERSHED PARAMETERS

                       1       2         3         4         5        6      7       8        9     10       11     12
CASE        STA       Q-2     Q-5      Q-10      Q-25      Q-50    M-LOG  S-DEV    AREA    SLOPE C-LEN   %-LKS   ELEV

  1       6-134.      57.    118.      166.      234.      288.    1.731   .397    62.7    143.0  15.4    1.00   7.78
  2       6-135.     293.    464.      574.      708.      802.    2.444   .258   280.0     75.2  23.1    1.01   8.01
  3       6-155.     366.    628.      818.     1070.     1264.    2.548   .292   348.0     46.0  42.0    1.14   7.05
  4       6-175.     171.    246.      298.      366.      418.    2.232   .189   312.0     36.5  34.7    1.00   7.21
  5       6-195.     830.   1032.     1157.     1308.     1415.    2.919   .113   538.0     53.3  39.5    1.07   7.28
  6       6-198.      20.     38.       53.       77.       97.    1.290   .338    10.8    279.0   9.8    1.00   7.11
  7       6-253.      83.    124.      154.      192.      223.    1.919   .208    41.4    144.0  13.0    1.00   7.05
  8       6-255.    7189.  10064.    11772.    13723.    15043.    3.841   .189  2476.0     15.4 112.6    1.18   7.14
  9       6-260.     166.    231.      274.      327.      366.    2.218   .172    36.0    207.0  12.8    1.69   7.69
 10       6-277.     127.    182.      221.      274.      315.    2.110   .180    39.5    197.0  13.8    1.00   7.03
 11       6-330.    1033.   1626.     2093.     2771.     3344.    3.025   .225   381.0     66.0  31.3    1.03   6.64
 12       6-430.     680.    844.      933.     1029.     1091.    2.822   .121    98.0    138.0  16.0    1.19   8.32
 13       6-432.     192.    268.      317.      377.      420.    2.277   .178    40.4    215.0  11.7    1.00   7.44
 14       6-433.      12.     19.       24.       31.       37.    1.065   .256     2.5    963.0   3.7    1.00   7.12
 15       6-435.    4766.   6047.     6756.     7530.     8036.    3.667   .134   825.0     16.8  59.5    1.03   7.96
 16       6-465.     228.    362.      461.      597.      705.    2.357   .239    49.0     96.0  13.2    1.00   6.11
 17       6-467.       7.     15.       22.       34.       44.     .867   .376     2.3    263.0   3.1    1.00   5.68
 18       6-470.     103.    168.      214.      276.      324.    2.003   .261    17.0    258.0   5.8    1.00   6.69
 19       6-480.     522.    794.      989.     1250.     1455.    2.717   .217   148.0    143.0  18.7    1.06   6.21
 20       6-485.     238.    378.      487.      643.      773.    2.383   .233    62.5     91.4  12.3    1.00   6.54
 21       6-500.     367.    462.      515.      572.      610.    2.554   .130    48.2     70.8  16.0    1.12   7.71
 22      6-1940.     216.    399.      560.      819.     1056.    2.349   .304    57.9    111.0  15.7    1.00   6.14
```

REGRESSION DATA FOR REGION III

COLUMNS 13 - 23 ARE WATERSHED PARAMETERS

CASE	STA	13 %-FR	14 P-WB	15 %>6//	16 P-SCS	17 P-IN	18 S-IDX	19 L/R*S	20 19/A67	21 15/18S	22 8/10S	23 16/18S
1	6-134.	29.0	12.0	100.0	16.3	1.70	3.700	1.29	.080	7.305	.264	1.191
2	6-135.	32.0	15.0	100.0	19.8	1.60	4.300	2.66	.061	5.408	.525	1.071
3	6-155.	31.0	12.0	95.0	16.4	1.30	3.900	6.19	.123	6.246	.197	1.078
4	6-175.	19.8	12.0	97.0	17.5	1.40	5.400	5.74	.122	3.326	.259	.600
5	6-195.	29.8	13.0	92.0	20.9	1.30	6.100	5.41	.080	2.472	.345	.562
6	6-198.	57.0	13.0	81.0	20.0	1.30	2.000	.59	.119	20.250	.112	5.000
7	6-253.	74.0	12.0	98.0	18.4	1.40	4.300	1.08	.089	5.300	.245	.995
8	6-255.	66.3	14.0	92.0	22.9	1.40	6.700	28.69	.153	2.049	.195	.510
9	6-260.	87.8	12.0	98.0	29.0	1.50	4.900	.89	.081	4.082	.220	1.208
10	6-277.	78.0	12.0	81.0	19.6	1.60	5.600	.98	.084	2.583	.207	.625
11	6-330.	90.1	12.0	81.0	21.5	1.50	5.200	3.85	.072	2.996	.389	.795
12	6-430.	61.5	20.0	100.0	40.1	1.50	3.900	1.36	.063	6.575	.383	2.636
13	6-432.	96.0	21.0	99.0	34.4	1.70	5.600	.80	.067	3.157	.295	1.097
14	6-433.	100.0	19.0	88.0	29.7	1.80	6.100	.12	.065	2.365	.181	.798
15	6-435.	84.3	18.0	96.0	37.7	1.60	4.900	14.52	.161	3.998	.233	1.570
16	6-465.	63.4	15.0	56.0	26.4	1.60	5.600	1.35	.099	1.786	.281	.842
17	6-467.	51.0	15.0	16.0	21.0	1.30	5.400	.19	.108	.549	.242	.720
18	6-470.	89.5	18.0	93.0	28.5	1.80	5.600	.36	.054	2.966	.505	.909
19	6-480.	66.0	18.0	52.0	24.3	1.50	5.200	1.56	.055	1.923	.423	.899
20	6-485.	74.9	14.0	63.0	31.9	1.90	4.100	1.29	.081	3.748	.413	1.898
21	6-500.	88.8	20.0	98.0	36.7	2.00	4.500	1.90	.142	4.840	.188	1.812
22	6-1940.	61.8	14.0	61.0	26.2	1.80	3.200	1.49	.098	5.957	.235	2.559

REGRESSION DATA FOR REGION IV

COLUMNS 1 - 7 ARE FLOOD FREQUENCY DATA

COLUMNS 8 - 12 ARE WATERSHED PARAMETERS

CASE	STA	1 Q-2	2 Q-5	3 Q-10	4 Q-25	5 Q-50	6 M-LOG	7 S-DEV	8 AREA	9 SLOPE	10 C-LEN	11 %-LKS	12 ELEV
1	6-375.	1309.	1583.	1729.	1885.	1985.	3.108	.106	420.0	34.2	38.9	1.48	7.92
2	6-1865.	4689.	5984.	6704.	7492.	8008.	3.660	.137	1006.0	32.4	68.5	14.82	8.68
3	6-1875.	369.	509.	592.	685.	748.	2.552	.180	50.4	165.0	12.9	1.00	8.34
4	6-1880.	8600.	10606.	11694.	12866.	13624.	3.925	.118	660.0	17.2	42.6	1.04	7.40
5	6-1905.	1032.	1322.	1484.	1662.	1778.	3.002	.139	200.0	186.0	14.0	1.25	7.95
6	6-1910.	1181.	1519.	1708.	1916.	2053.	3.060	.141	202.0	176.0	14.9	1.25	7.94
7	6-1915.	16956.	20722.	22751.	24929.	26332.	4.220	.113	2623.0	25.3	130.5	6.40	8.44
8	6-1975.	3256.	3782.	4076.	4404.	4624.	3.510	.080	226.0	104.0	30.8	1.22	8.51
9	6-2000.	5146.	6821.	7929.	9334.	10385.	3.714	.143	523.0	55.6	55.2	1.13	7.57
10	6-2050.	6316.	8192.	9386.	10852.	11920.	3.800	.134	975.0	73.3	60.0	1.43	7.22
11	6-2075.	7385.	9116.	10129.	11293.	12092.	3.865	.112	1154.0	76.3	75.6	1.54	7.43
12	6-2095.	1157.	1672.	2027.	2490.	2845.	3.063	.190	124.0	243.0	20.2	1.81	9.54
13	6-2875.	387.	729.	1030.	1504.	1934.	2.597	.318	98.3	282.0	189.0	1.00	4.24
14	6-2890.	963.	1354.	1637.	2023.	2330.	2.992	.169	193.0	196.0	24.8	1.00	7.83
15	6-2900.	364.	698.	1002.	1498.	1961.	2.577	.323	111.0	127.0	16.8	1.34	5.57
16	6-2905.	1162.	1833.	2362.	3131.	3783.	3.076	.226	428.0	135.0	43.3	1.04	6.14
17	6-2915.	414.	601.	740.	933.	1090.	2.626	.186	80.7	238.0	21.5	1.00	6.36

REGRESSION DATA FOR REGION IV

COLUMNS 13 - 23 ARE WATERSHED PARAMETERS

CASE	STA	13 %-FR	14 P-WB	15 %>6//	16 P-SCS	17 P-IN	18 S-IDX	19 L/R*S	20 19/A67	21 15/18S	22 8/10S	23 16/18S
1	6-375.	94.8	24.0	100.0	40.2	1.40	9.000	6.65	.116	1.235	.278	.496
2	6-1865.	71.6	27.0	100.0	27.0	1.50	9.000	12.03	.117	1.235	.214	.333
3	6-1875.	96.7	16.0	100.0	16.0	1.40	9.000	1.00	.073	1.235	.303	.198
4	6-1880.	79.2	24.0	91.0	24.0	1.40	9.000	10.27	.133	1.123	.364	.296
5	6-1905.	81.3	19.0	99.0	19.0	1.40	9.000	1.03	.029	1.222	1.020	.235
6	6-1910.	80.2	19.0	99.0	19.0	1.40	9.000	1.12	.032	1.222	.910	.235
7	6-1915.	79.2	23.0	97.0	23.0	1.40	7.900	25.94	.133	1.554	.154	.369
8	6-1975.	66.3	23.0	92.0	42.3	2.30	3.900	3.02	.080	6.049	.238	2.781
9	6-2000.	58.9	20.0	76.0	30.9	2.20	4.100	7.40	.112	4.521	.172	1.838
10	6-2050.	55.6	24.0	54.0	33.2	2.10	3.700	7.01	.070	3.944	.271	2.425
11	6-2075.	60.9	17.0	80.0	17.0	1.70	5.500	8.65	.077	2.645	.202	.562
12	6-2095.	41.0	18.0	100.0	41.0	2.40	3.200	1.30	.051	9.766	.304	4.004
13	6-2875.	3.8	15.0	6.0	17.5	1.80	1.900	11.25	.520	1.662	.003	4.848
14	6-2890.	88.0	20.0	94.0	20.0	2.30	6.700	1.77	.052	2.094	.314	.446
15	6-2900.	27.8	15.0	16.0	18.0	2.10	3.500	1.49	.064	1.306	.393	1.469
16	6-2905.	46.9	19.0	48.0	18.5	2.20	5.400	3.73	.064	1.646	.228	.634
17	6-2915.	34.3	15.0	53.0	25.0	2.20	3.400	1.39	.074	4.585	.175	2.163

REGRESSION DATA FOR REGION V

COLUMNS 1 - 7 ARE FLOOD FREQUENCY DATA

COLUMNS 8 - 12 ARE WATERSHED PARAMETERS

CASE	STA	1 Q-2	2 Q-5	3 Q-10	4 Q-25	5 Q-50	6 M-LOG	7 S-DEV	8 AREA	9 SLOPE	10 C-LEN	11 %-LKS	12 ELEV
1	6-778.	77.	174.	282.	498.	741.	1.852	.440	21.8	86.7	10.0	1.00	4.02
2	6-893.	96.	243.	377.	581.	753.	1.935	.521	21.1	49.0	6.8	1.00	3.51
3	6-1263	125.	365.	600.	972.	1300.	2.048	.600	220.0	43.3	48.5	1.00	4.25
4	6-1289.	170.	323.	419.	526.	594.	2.165	.404	16.2	25.5	6.2	1.00	2.90
5	6-1295.	324.	710.	976.	1290.	1497.	2.428	.496	421.0	25.0	50.1	1.02	4.14
6	6-1297.	99.	239.	343.	472.	560.	1.890	.564	2.3	29.2	3.2	1.01	2.91
7	6-1298.	54.	122.	169.	227.	265.	1.636	.518	.8	29.6	1.8	1.01	2.90
8	6-1306.	130.	298.	417.	560.	655.	2.013	.526	36.5	31.1	11.7	1.01	2.87
9	6-1307.	750.	2304.	3643.	5440.	6746.	2.754	.713	317.0	17.2	46.4	1.09	3.05
10	6-1308.	30.	74.	106.	148.	176.	1.379	.571	.7	45.5	1.4	1.00	2.80
11	6-1308.5	35.	87.	126.	174.	207.	1.439	.579	1.9	34.8	1.5	1.00	2.80
12	6-1309.	16.	37.	51.	69.	81.	1.108	.520	.6	54.1	.5	1.00	2.81
13	6-1309.5	1627.	3146.	4113.	5198.	5894.	3.143	.416	1224.0	9.4	83.7	1.11	2.86
14	6-1310.	3515.	8869.	12926.	17967.	21437.	3.451	.584	2554.0	19.3	96.7	1.10	2.87
15	6-1395	370.	1395.	2500.	4320.	5900.	2.478	.778	1805.0	17.8	73.7	1.18	3.20
16	6-1545.	801.	1603.	2125.	2719.	3104.	2.830	.440	670.0	20.5	74.9	1.22	3.50
17	6-1551.	82.	137.	170.	206.	229.	1.868	.312	6.6	15.6	4.2	1.00	2.50
18	6-1553.	82.	171.	234.	309.	361.	1.840	.460	3.4	103.0	2.5	1.00	2.48
19	6-1560	229.	1035.	2010.	3710.	5350.	2.218	.884	458.0	18.3	36.3	1.94	2.82
20	6-1723.	56.	167.	280.	471.	647.	1.709	.595	11.1	51.7	11.7	1.00	2.56
21	6-1765.	403.	1565.	3046.	6003.	9148.	2.565	.733	251.0	26.7	31.5	1.00	2.57
22	6-1770.5	173.	384.	533.	711.	830.	2.152	.495	12.4	53.7	8.9	1.00	2.91
23	6-1771.	222.	614.	928.	1332.	1616.	2.239	.643	54.0	38.5	17.3	1.01	2.91
24	6-1771.5	698.	1172.	1446.	1738.	1918.	2.791	.328	216.0	12.2	22.9	1.01	2.81
25	6-1772.	149.	272.	348.	431.	483.	2.112	.379	90.2	37.3	14.7	1.00	2.98
26	6-1773.	15.	38.	56.	78.	94.	1.064	.598	.3	80.0	1.0	1.00	2.62
27	6-1773.5	35.	69.	90.	114.	130.	1.477	.423	5.7	74.3	4.7	1.00	2.84
28	6-1774.	136.	332.	477.	656.	777.	2.041	.564	29.9	33.3	13.2	1.00	2.81
29	6-1775.	852.	3725.	6779.	11437.	15136.	2.779	.933	547.0	43.9	39.5	1.08	2.81
30	6-3287	11.	32.	53.	86.	115.	.971	.600	5.0	78.4	4.9	1.00	2.25
31	6-3292.	306.	1160.	2168.	4010.	5805.	2.406	.757	233.0	27.2	34.2	1.08	2.60
32	6-3364.5	82.	179.	257.	366.	454.	1.877	.437	3.9	57.7	3.5	1.00	2.90

REGRESSION DATA FOR REGION V

COLUMNS 13 - 23 ARE WATERSHED PARAMETERS

CASE	STA	13 %-FR	14 P-WB	15 %>6//	16 P-SCS	17 P-IN	18 S-IDX	19 L/R*S	20 19/A67	21 15/18S	22 8/10S	23 16/18S
1	6-778.	1.0	14.0	1.0	15.0	1.70	2.500	1.07	.136	.160	.218	2.400
2	6-893.	1.0	13.0	1.0	12.0	1.70	2.500	.97	.126	.160	.456	1.920
3	6-1263	9.0	13.0	6.0	14.0	1.35	3.200	7.37	.199	.586	.094	1.367
4	6-1289.	1.0	13.0	1.0	13.0	1.30	1.900	1.23	.190	.277	.421	3.601
5	6-1295.	8.0	16.0	1.0	17.2	1.55	2.100	10.02	.175	.227	.168	3.900
6	6-1297.	1.0	13.0	1.0	13.0	1.40	1.900	.59	.337	.277	.227	3.601
7	6-1298.	1.0	13.0	1.0	13.0	1.40	1.900	.33	.381	.277	.250	3.601
8	6-1306.	1.0	13.0	1.0	12.5	1.30	1.900	2.10	.188	.277	.267	3.463
9	6-1307.	1.0	12.0	1.0	12.0	1.35	2.500	11.19	.236	.160	.147	1.920
10	6-1308.	1.0	12.0	1.0	12.0	1.45	2.500	.21	.252	.160	.383	1.920
11	6-1308.5	1.0	12.0	1.0	12.0	1.45	2.500	.25	.165	.160	.844	1.920
12	6-1309.	1.0	12.0	1.0	12.0	1.45	2.500	.07	.096	.160	2.400	1.920
13	6-1309.5	1.0	12.0	1.0	13.0	1.40	2.500	27.30	.233	.160	.175	2.080
14	6-1310.	1.0	12.0	1.0	12.5	1.40	2.500	22.01	.115	.160	.273	2.000
15	6-1395	3.0	12.0	1.0	12.8	1.70	2.700	17.47	.115	.137	.332	1.756
16	6-1545.	3.7	14.0	1.0	14.8	1.80	3.700	16.54	.211	.073	.119	1.081
17	6-1551.	1.0	13.0	1.0	11.8	1.55	3.300	1.06	.299	.092	.376	1.084
18	6-1553.	1.0	13.0	1.0	11.8	1.55	3.300	.25	.108	.092	.547	1.084
19	6-1560	1.0	12.0	1.0	12.0	1.60	2.500	8.49	.140	.160	.348	1.920
20	6-1723.	1.0	12.0	1.0	11.8	1.85	2.700	1.63	.324	.137	.081	1.619
21	6-1765.	1.0	13.0	1.0	11.9	1.60	2.500	6.10	.150	.160	.253	1.904
22	6-1770.5	1.0	12.0	1.0	13.6	1.40	2.000	1.21	.225	.250	.157	3.400
23	6-1771.	1.0	12.0	1.0	13.5	1.40	2.000	2.79	.193	.250	.180	3.375
24	6-1771.5	1.0	12.0	1.0	13.1	1.40	1.800	6.56	.179	.309	.412	4.043
25	6-1772.	1.0	12.0	1.0	14.1	1.40	1.900	2.41	.118	.277	.417	3.906
26	6-1773.	1.0	12.0	1.0	11.5	1.45	1.800	.11	.256	.309	.290	3.549
27	6-1773.5	1.0	12.0	1.0	13.5	1.45	1.900	.55	.169	.277	.260	3.740
28	6-1774.	1.0	12.0	1.0	13.5	1.50	1.900	2.29	.235	.277	.172	3.740
29	6-1775.	1.0	12.0	1.0	13.2	1.45	2.100	5.96	.087	.227	.351	2.993
30	6-3287	1.0	13.0	1.0	13.0	1.60	3.500	.55	.188	.082	.209	1.061
31	6-3292.	1.0	14.0	1.0	13.5	1.55	3.500	6.56	.170	.082	.199	1.102
32	6-3364.5	1.0	14.0	1.0	14.0	1.60	3.000	.46	.186	.111	.317	1.556

REGRESSION DATA FOR REGION VI

COLUMNS 1 - 7 ARE FLOOD FREQUENCY DATA

COLUMNS 8 - 12 ARE WATERSHED PARAMETERS

CASE	STA	1 Q-2	2 Q-5	3 Q-10	4 Q-25	5 Q-50	6 M-LOG	7 S-DEV	8 AREA	9 SLOPE	10 C-LEN	11 %-LKS	12 ELEV
1	6-1445.	1438.	2678.	3446.	4295.	4832.	3.093	.393	753.0	13.3	70.5	2.15	3.48
2	6-1450.	150.	521.	867.	1354.	1719.	2.046	.786	59.0	15.4	17.3	1.34	2.90
3	6-1455.	1116.	2520.	3509.	4686.	5471.	2.961	.513	818.0	14.0	71.6	2.07	3.49
4	6-1480.	596.	1062.	1343.	1649.	1841.	2.715	.366	270.0	27.2	44.0	1.19	4.07
5	6-1500.	357.	1183.	1925.	2946.	3700.	2.429	.757	60.2	11.9	22.4	2.35	2.95
6	6-1505.	333.	838.	1219.	1692.	2016.	2.426	.584	89.5	14.0	19.0	1.42	3.00
7	6-1510.	203.	514.	750.	1044.	1246.	2.212	.588	56.7	26.3	20.2	2.41	3.00
8	6-1685.	585.	1265.	1815.	2580.	3180.	2.731	.432	241.0	13.5	39.5	1.00	2.91
9	6-1690.	258.	700.	1140.	1755.	2310.	2.364	.563	73.5	20.8	22.3	1.00	2.81
10	6-1695.	928.	2060.	3070.	4450.	5530.	2.930	.458	328.0	12.3	43.3	1.08	2.87
11	6-1700.	469.	1142.	1729.	2588.	3300.	2.630	.500	182.0	20.2	16.3	1.03	2.83
12	6-1780.	750.	1835.	2760.	4150.	5270.	2.834	.501	362.0	15.3	39.2	1.05	2.95
13	6-1785.	582.	1490.	2310.	3550.	4580.	2.721	.529	534.0	5.9	56.4	2.78	2.80
14	6-1795.	205.	500.	757.	1133.	1441.	2.271	.500	139.0	11.5	23.2	1.00	3.00
15	6-1800.	608.	1590.	2480.	3840.	4990.	2.738	.541	428.0	5.4	49.8	1.07	2.90
16	6-1810.	4340.	11300.	17650.	27200.	35350.	3.592	.538	3174.0	6.4	145.1	1.39	2.73
17	6-1825.	893.	2170.	3290.	4930.	6270.	2.909	.501	279.0	11.4	35.1	1.00	2.51
18	6-1830.	1145.	2480.	3550.	5020.	6200.	3.023	.433	850.0	6.4	77.4	1.08	2.46
19	6-1831	119.	220.	292.	386.	457.	2.049	.344	9.4	38.9	4.8	1.00	2.38
20	6-1832	323.	935.	1178.	1761.	2218.	2.463	.500	19.9	36.1	8.5	1.00	2.33
21	6-1833	22.	61.	83.	124.	158.	1.310	.500	7.1	88.2	4.5	1.00	2.44
22	6-1834	69.	171.	258.	386.	491.	1.804	.500	16.9	51.9	10.3	1.00	2.33

REGRESSION DATA FOR REGION VI

COLUMNS 13 - 23 ARE WATERSHED PARAMETERS

CASE	STA	13 %-FR	14 P-WB	15 %>6//	16 P-SCS	17 P-IN	18 S-IDX	19 L/R*S	20 19/A67	21 15/18S	22 8/10S	23 16/18S
1	6-1445.	15.0	13.0	1.0	13.0	1.60	3.200	19.33	.228	.098	.152	1.270
2	6-1450.	1.0	12.0	1.0	12.0	1.60	3.000	4.41	.287	.111	.197	1.333
3	6-1455.	1.0	13.0	1.0	13.0	1.60	3.000	19.14	.214	.111	.160	1.444
4	6-1480.	40.0	16.0	1.0	16.0	1.60	3.200	8.44	.198	.098	.139	1.562
5	6-1500.	1.0	12.0	1.0	12.0	1.60	2.800	6.49	.417	.128	.120	1.531
6	6-1505.	1.0	12.0	1.0	11.8	1.60	2.500	5.08	.250	.160	.248	1.888
7	6-1510.	1.0	12.0	1.0	11.8	1.60	2.500	3.94	.263	.160	.139	1.888
8	6-1685.	1.0	12.0	1.0	12.0	1.70	3.300	10.75	.273	.092	.154	1.102
9	6-1690.	2.0	12.0	1.0	12.0	1.60	3.300	4.89	.275	.092	.148	1.102
10	6-1695.	1.0	12.0	1.0	12.0	1.60	3.100	12.35	.255	.104	.175	1.249
11	6-1700.	1.0	12.0	1.0	12.0	1.60	3.300	3.63	.111	.092	.685	1.102
12	6-1780.	1.0	12.0	1.0	12.5	1.70	3.300	10.02	.193	.092	.236	1.148
13	6-1785.	1.0	12.0	1.0	13.5	1.80	3.300	23.22	.345	.092	.168	1.240
14	6-1795.	1.0	12.0	1.0	12.0	1.70	3.300	6.84	.251	.092	.258	1.102
15	6-1800.	1.0	12.0	1.0	12.0	1.70	2.200	21.43	.370	.207	.173	2.479
16	6-1810.	1.0	12.0	1.0	12.6	1.70	2.800	57.22	.258	.128	.151	1.607
17	6-1825.	1.0	11.0	1.0	14.5	1.80	3.300	10.40	.239	.092	.226	1.331
18	6-1830.	1.0	12.0	1.0	14.0	1.80	3.000	30.60	.333	.111	.142	1.556
19	6-1831	1.0	12.0	1.0	14.0	1.90	3.000	.77	.172	.111	.408	1.556
20	6-1832	1.0	12.0	1.0	14.0	1.90	3.000	1.41	.191	.111	.275	1.556
21	6-1833	1.0	12.0	1.0	14.0	1.90	3.000	.48	.129	.111	.348	1.556
22	6-1834	1.0	12.0	1.0	14.0	1.90	3.000	1.43	.215	.111	.159	1.556

```
                                                  REGRESSION DATA FOR REGION VII

          COLUMNS 1 - 7 ARE FLOOD FREQUENCY DATA                          COLUMNS 8 - 12 ARE WATERSHED PARAMETERS

                     1       2          3          4          5        6       7        8       9     10       11      12
CASE       STA      Q-2     Q-5       Q-10       Q-25       Q-50     M-LOG   S-DEV    AREA    SLOPE C-LEN   %-LKS    ELEV

  1   6-2162.      72.    175.       281.       464.       643.    1.845    .462      8.1    88.2    2.2    1.00   3.75
  2   6-2163.      70.    174.       280.       466.       649.    1.835    .468      1.5   106.0    7.5    1.00   3.99
  3   6-2165.     612.   1137.      1571.      2219.      2774.    2.787    .319    435.0    42.9   46.7    1.00   4.55
  4  6-2950.5    1859.   2564.      2921.      3273.      3478.    3.235    .203    614.0     7.2   67.0    1.27   2.91
  5   6-2952.       9.     23.        39.        69.        99.     .929    .515      1.6   225.0    2.7    1.00   3.61
  6   6-2960.     347.    671.       947.      1368.      1737.    2.538    .338   1260.0    13.7  127.0    1.00   3.61
  7   6-3069.     117.    444.       918.      2033.      3443.    2.092    .669     36.3    15.8   12.7    1.00   4.16
  8  6-3069.5      97.    242.       400.       692.       995.    1.999    .460      6.0   125.0    3.8    1.00   4.23
  9   6-3082.      26.     67.       102.       153.       194.    1.369    .533       .1    71.4     .9    1.00   2.98
 10   6-3083.     258.    692.      1086.      1677.      2167.    2.354    .564     10.9    40.0    6.0    1.00   3.06
 11   6-3247.      42.    101.       149.       218.       272.    1.575    .498     10.6    48.0    5.0    1.00   3.30
 12   6-3255.    1131.   1705.      2065.      2490.      2785.    3.034    .231   1974.0     8.0  128.8    1.08   3.93
 13   6-3329.     326.    832.      1291.      1987.      2575.    2.467    .526       .7    76.9    1.8    1.00   3.55
 14   6-3340.    1742.   3192.      4231.      5576.      6578.    3.213    .340    904.0     9.3   86.2    1.11   3.91
 15   6-3341.     411.    847.      1190.      1660.      2029.    2.578    .404      9.1    30.8    5.2    1.66   3.71
 16   6-3342.     727.   1578.      2265.      3226.      3989.    2.825    .435    123.0    12.8   20.8    1.29   3.69
 17   6-3365.     971.   3370.      6029.     10664.     15013.    2.927    .697    351.0     5.0   60.0    1.05   3.02
```

REGRESSION DATA FOR REGION VII

COLUMNS 13 - 23 ARE WATERSHED PARAMETERS

CASE	STA	13 %-FR	14 P-WB	15 %>6//	16 P-SCS	17 P-IN	18 S-IDX	19 L/R*S	20 19/A67	21 15/18S	22 8/10S	23 16/18S
1	6-2162.	1.0	11.0	1.0	14.0	1.60	2.500	.23	.057	.160	1.682	2.240
2	6-2163.	1.0	12.0	1.0	14.0	1.60	2.500	.73	.545	.160	.027	2.240
3	6-2165.	14.5	10.0	13.0	15.2	1.90	2.700	7.13	.122	1.783	.199	2.085
4	6-2950.5	1.1	12.0	1.0	11.5	1.20	2.700	24.97	.338	.137	.137	1.578
5	6-2952.	100.0	14.0	1.0	14.0	1.50	2.000	.18	.132	.250	.217	3.500
6	6-2960.	42.0	14.0	1.0	14.7	1.50	3.000	34.31	.287	.111	.078	1.633
7	6-3069.	1.0	15.0	1.0	13.5	1.50	2.000	3.20	.288	.250	.225	3.375
8	6-3069.5	1.0	15.0	1.0	15.0	1.50	2.000	.34	.102	.250	.418	3.750
9	6-3082.	1.0	14.0	1.0	14.0	1.50	2.500	.11	.398	.160	.173	2.240
10	6-3083.	2.7	14.0	1.0	14.0	1.50	2.500	.95	.191	.160	.303	2.240
11	6-3247.	5.9	15.0	1.0	14.0	1.50	2.500	.72	.148	.160	.424	2.240
12	6-3255.	8.4	15.0	1.0	15.0	1.70	3.300	45.54	.282	.092	.119	1.377
13	6-3329.	1.0	16.0	1.0	14.0	1.70	3.000	.21	.266	.111	.210	1.556
14	6-3340.	9.0	16.0	1.0	16.0	1.80	3.200	28.31	.296	.098	.122	1.562
15	6-3341.	1.0	16.0	1.0	15.0	1.80	3.000	.94	.214	.111	.336	1.667
16	6-3342.	1.0	16.0	1.0	15.0	1.80	3.000	5.81	.231	.111	.284	1.667
17	6-3365.	1.0	14.0	1.0	14.0	1.60	2.200	26.83	.529	.207	.097	2.893

REGRESSION DATA FOR REGION VIII

COLUMNS 1 - 7 ARE FLOOD FREQUENCY DATA   COLUMNS 8 - 12 ARE WATERSHED PARAMETERS

CASE	STA	1 Q-2	2 Q-5	3 Q-10	4 Q-25	5 Q-50	6 M-LOG	7 S-DEV	8 AREA	9 SLOPE	10 C-LEN	11 %-LKS	12 ELEV
1	12-3008.	154.	197.	218.	238.	249.	2.163	.155	17.9	346.0	9.8	1.19	4.94
2	12-3013.	1546.	2023.	2256.	2481.	2611.	3.161	.169	440.0	36.4	40.2	1.77	4.17
3	12-3020.	3374.	4590.	5244.	5927.	6352.	3.504	.185	780.0	22.9	58.1	1.21	4.19
4	12-3233.	21.	60.	105.	195.	292.	1.318	.543	4.9	136.0	5.9	1.00	6.06
5	12-3235.	162.	256.	327.	423.	501.	2.208	.237	40.6	315.0	8.7	1.00	6.93
6	12-3241.	343.	467.	549.	652.	728.	2.536	.159	39.5	105.0	12.7	2.75	7.60
7	12-3247.	58.	118.	172.	256.	332.	1.761	.370	4.6	292.0	4.8	1.00	4.82
8	12-3248.	8.	14.	18.	23.	27.	.924	.247	12.6	237.0	8.2	1.00	5.43
9	12-3300.	371.	513.	607.	727.	817.	2.569	.167	71.3	89.1	13.5	1.28	6.98
10	12-3320.	920.	1213.	1379.	1565.	1687.	2.951	.155	123.0	78.9	20.2	1.46	7.18
11	12-3350.	1969.	3045.	3826.	4880.	5712.	3.294	.225	481.0	25.2	47.7	1.04	5.89
12	12-3355.	500.	862.	1159.	1606.	1993.	2.708	.274	116.0	111.0	15.7	1.00	5.88
13	12-3385.	5053.	7353.	8759.	10396.	11520.	3.686	.211	1274.0	13.4	79.7	1.32	5.76
14	12-3399.	89.	126.	149.	175.	192.	1.931	.198	7.5	598.0	6.3	1.00	5.43
15	12-3400.	8605.	12531.	14929.	17722.	19639.	3.917	.211	2290.0	14.8	116.9	1.62	5.71
16	12-3402.	14.	22.	28.	35.	40.	1.120	.268	5.5	485.0	5.4	1.00	4.86
17	12-3434.	1940.	2756.	3248.	3814.	4200.	3.271	.197	381.0	67.9	35.3	1.15	6.45
18	12-3440.	6115.	8280.	9536.	10951.	11896.	3.772	.170	1049.0	35.3	47.2	1.15	6.49
19	12-3443.	6.	9.	11.	14.	16.	.774	.234	6.3	412.0	5.0	1.00	5.49
20	12-3458.	134.	200.	242.	291.	325.	2.106	.227	6.0	793.0	6.1	2.70	6.82
21	12-3465.	592.	740.	825.	921.	987.	2.766	.120	87.8	186.0	12.9	1.14	6.80
22	12-3475.	595.	712.	775.	841.	884.	2.766	.101	26.4	172.0	12.3	1.33	6.73
23	12-3485.	95.	122.	137.	155.	167.	1.973	.131	22.4	551.0	7.5	1.00	6.37
24	12-3500.	752.	933.	1031.	1137.	1206.	2.866	.121	26.8	278.0	11.8	1.25	6.43
25	12-3502.	103.	158.	192.	233.	262.	1.994	.238	3.4	1011.0	3.5	1.00	6.77
26	12-3505.	759.	982.	1107.	1245.	1336.	2.868	.145	28.9	275.0	9.2	1.35	6.67
27	12-3510.	332.	493.	597.	726.	820.	2.511	.213	74.0	171.0	16.7	1.00	6.57
28	12-3522.	9.	20.	29.	43.	54.	.908	.462	4.2	516.0	4.6	1.00	4.54
29	12-3534.	29.	52.	69.	91.	108.	1.426	.339	8.0	580.0	4.3	1.00	4.76
30	12-3538.	66.	109.	138.	173.	198.	1.798	.278	12.2	416.0	9.1	1.00	4.72

```
31 123538.5   33.    47.        55.       65.       71.   1.508  .191    2.7   590.0   3.4   1.00  4.32
32 12-3540. 3910.  5615.      6647.     7843.     8660.   3.574  .204  303.0    45.0  37.1   1.01  4.52
33 12-3541.  145.   209.       247.      291.      322.   2.144  .203   14.7   227.0  10.8   1.00  4.87
34 12-3639.   15.    22.        26.       29.       31.   1.152  .226    6.2   958.0   3.7   1.20  4.58
35 12-3650. 1849.  2944.      3619.     4394.     4914.   3.235  .273  524.0    19.8  50.5   1.37  4.32
36 12-3700. 5229.  6495.      7186.     7933.     8417.   3.708  .122  671.0    36.3  84.5   2.85  5.02
37 12-3705.   48.    84.       109.      141.      164.   1.650  .317   20.9   175.0   6.8   1.00  4.37
38 12-3709.    9.    19.        27.       39.       48.    .903  .438    2.6   900.0   4.1   1.20  5.46
39 12-3743.  102.   160.       198.      245.      277.   1.985  .257   28.0   258.0   8.8   1.00  4.57
40 12-3757.   25.    48.        64.       85.      101.   1.376  .350    3.3   543.0   3.7   1.00  4.18
41 12-3895. 2555.  3738.      4465.     5313.     5896.   3.389  .213  642.0    21.9  48.7   1.60  4.71
42 12-3907. 1707.  2185.      2452.     2745.     2937.   3.220  .139  182.0   118.0  21.5   1.10  4.41
```

REGRESSION DATA FOR REGION VIII

COLUMNS 13 - 23 ARE WATERSHED PARAMETERS

CASE	STA	13 %-FR	14 P-WB	15 %>6//	16 P-SCS	17 P-IN	18 S-IDX	19 L/R*S	20 19/A67	21 15/18S	22 8/10S	23 16/18S
1	12-3008.	98.0	19.0	31.0	53.3	1.70	7.500	.53	.076	.551	.186	.948
2	12-3013.	98.8	20.0	6.0	34.3	1.60	7.500	6.66	.113	.107	.272	.610
3	12-3020.	92.4	19.0	1.0	30.3	1.70	7.200	12.14	.140	.019	.231	.584
4	12-3233.	25.1	12.0	56.0	13.5	1.20	3.000	.51	.176	6.222	.139	1.500
5	12-3235.	89.3	13.0	89.0	17.0	1.50	6.400	.49	.041	2.173	.536	.415
6	12-3241.	95.7	14.0	94.0	35.3	1.70	7.000	1.24	.106	1.918	.245	.720
7	12-3247.	16.0	13.0	7.0	12.0	1.20	2.500	.28	.101	1.120	.200	1.920
8	12-3248.	61.0	13.0	20.0	18.0	1.40	3.300	.53	.098	1.837	.187	1.653
9	12-3300.	99.0	14.0	84.0	31.9	1.60	7.200	1.43	.082	1.620	.391	.615
10	12-3320.	94.3	18.0	90.0	36.0	1.60	7.000	2.27	.090	1.837	.301	.735
11	12-3350.	95.6	15.0	48.0	29.0	1.60	7.000	9.50	.152	.980	.211	.592
12	12-3355.	75.4	13.0	37.0	23.3	1.40	5.600	1.49	.062	1.180	.471	.743
13	12-3385.	84.4	15.0	38.0	33.8	1.60	7.000	21.77	.181	.776	.201	.690
14	12-3399.	79.3	16.0	34.0	32.0	1.50	6.100	.26	.067	.914	.188	.860
15	12-3400.	88.5	16.0	36.0	31.9	1.60	7.500	30.39	.170	.640	.168	.567
16	12-3402.	89.7	15.0	16.0	20.0	1.50	4.000	.25	.079	1.000	.188	1.250
17	12-3434.	96.2	19.0	62.0	30.3	1.60	7.900	4.28	.080	.993	.306	.485
18	12-3440.	96.4	22.0	62.0	34.1	1.70	8.200	7.94	.075	.922	.471	.507
19	12-3443.	78.7	14.0	26.0	21.0	1.40	3.300	.25	.072	2.388	.251	1.928
20	12-3458.	64.1	21.0	81.0	71.8	2.10	5.600	.22	.065	2.583	.162	2.290
21	12-3465.	100.0	14.0	83.0	35.2	1.60	7.000	.95	.047	1.694	.528	.718
22	12-3475.	93.3	31.0	68.0	73.4	2.20	6.700	.94	.105	1.515	.174	1.635
23	12-3485.	90.0	14.0	64.0	30.0	1.60	3.000	.32	.040	7.111	.398	3.333
24	12-3500.	100.0	34.0	69.0	70.4	2.10	7.000	.71	.078	1.408	.192	1.437
25	12-3502.	87.1	20.0	80.0	65.0	1.90	6.400	.11	.049	1.953	.275	1.587
26	12-3505.	100.0	29.0	71.0	75.4	2.10	7.000	.55	.058	1.449	.341	1.539
27	12-3510.	83.8	14.0	71.0	32.0	1.60	3.300	1.28	.071	6.520	.265	2.938
28	12-3522.	80.0	14.0	4.0	32.0	1.50	5.400	.20	.078	.137	.197	1.097
29	12-3534.	82.6	14.0	9.0	29.9	2.00	3.300	.18	.044	.826	.434	2.746
30	12-3538.	87.8	23.0	14.0	39.9	2.30	6.100	.45	.083	.376	.147	1.072

```
31 123538.5   90.0     31.0   1.0     57.0   2.00   4.300    .14   .072    .054   .235   3.083
32 12-3540.  100.0     32.0   2.0     55.5   2.00   8.200   5.53   .120    .030   .220    .825
33 12-3541.   90.0     34.0   3.0     54.6   2.00   6.100    .72   .118    .081   .126   1.467
34 12-3639.   98.0     19.0  22.0     40.9   1.60   7.000    .12   .035    .449   .451    .835
35 12-3650.   98.5     20.0   4.0     28.5   1.70   7.000  11.35   .171    .082   .205    .582
36 12-3700.   90.8     23.0  27.0     47.9   1.70   8.900  14.03   .179    .341   .094    .605
37 12-3705.   95.0     16.0   1.0     21.0   1.70   6.100    .51   .067    .027   .452    .564
38 12-3709.   90.0     20.0  46.0     35.0   1.80   5.600    .14   .073   1.467   .152   1.116
39 12-3743.   94.2     12.0   3.0     26.9   1.80   5.600    .55   .059    .096   .362    .858
40 12-3757.   95.0     11.0   1.0     20.0   2.00   4.700    .16   .071    .045   .240    .905
41 12-3895.  100.0     14.0   6.0     36.6   1.80   6.400  10.41   .137    .146   .271    .894
42 12-3907.   99.2     33.0   4.0     50.9   2.10   7.500   1.98   .061    .071   .394    .905
```

REGRESSION DATA FOR REGION IX

COLUMNS 1 - 7 ARE FLOOD FREQUENCY DATA COLUMNS 8 - 12 ARE WATERSHED PARAMETERS

CASE	STA	1 Q-2	2 Q-5	3 Q-10	4 Q-25	5 Q-50	6 M-LOG	7 S-DEV	8 AREA	9 SLOPE	10 C-LEN	11 %-LKS	12 ELEV
1	12-3005.	799.	1138.	1314.	1489.	1592.	2.866	.224	112.0	87.6	18.3	1.01	4.55
2	12-3017.	8.	13.	15.	18.	20.	.825	.315	1.1	1724.0	1.6	1.00	4.32
3	12-3018.	73.	108.	127.	147.	158.	1.822	.249	6.0	788.0	4.2	1.00	4.91
4	12-3024.	17.	25.	30.	34.	37.	1.186	.253	1.1	674.0	2.5	1.00	3.76
5	12-3025.	706.	1173.	1441.	1726.	1900.	2.796	.320	23.6	254.0	9.4	2.06	5.26
6	12-3035.	2525.	2940.	3128.	3302.	3398.	3.386	.096	210.0	31.6	27.5	2.34	4.08
7	123042.5	27.	38.	44.	50.	54.	1.390	.222	2.6	578.0	3.1	1.00	4.23
8	12-3043.	147.	182.	199.	215.	224.	2.143	.138	5.7	501.0	5.1	1.00	4.73
9	12-3044.	185.	240.	267.	292.	307.	2.241	.163	7.7	501.0	5.1	1.00	4.47
10	12-3045.	7482.	9242.	10072.	10857.	11303.	3.852	.134	766.0	32.9	65.0	1.04	5.05
11	12-3550.	7693.	10159.	11450.	12780.	13596.	3.864	.167	450.0	31.7	42.0	1.01	6.01
12	12-3555.	20362.	25862.	28668.	31512.	33239.	4.290	.143	1548.0	8.1	99.0	2.03	5.12
13	12-3560.	146.	216.	264.	328.	377.	2.166	.200	8.1	321.0	5.4	1.00	5.86
14	12-3570.	9574.	12788.	14688.	16867.	18354.	3.970	.159	510.0	36.7	60.0	1.15	5.90
15	12-3574.	2.	5.	7.	10.	12.	.303	.441	.1	564.0	.6	1.00	3.60
16	12-3575.	18134.	23519.	26870.	30907.	33795.	4.256	.136	943.0	13.4	99.5	1.27	5.85
17	12-3585.	20544.	26516.	29869.	33562.	35992.	4.301	.143	1128.0	11.7	102.2	2.20	5.80
18	12-3590.	14888.	19025.	21388.	24037.	25811.	4.164	.135	958.0	25.3	76.5	1.23	6.13
19	12-3600.	1194.	1747.	2114.	2574.	2914.	3.070	.202	47.0	121.0	15.4	1.10	5.30
20	12-3610.	1767.	2509.	2955.	3467.	3816.	3.231	.197	71.3	124.0	13.0	1.01	5.51
21	12-3615.	1144.	1655.	1967.	2329.	2578.	3.041	.208	27.0	328.0	9.0	3.40	5.43
22	12-3625.	25613.	32082.	35723.	39766.	42451.	4.400	.124	1663.0	13.1	125.9	1.28	5.76
23	12-3630.	69770.	88479.	98837.	110150.	117538.	4.833	.133	4464.0	8.1	115.0	1.94	5.73
24	12-3660.	902.	1165.	1312.	1474.	1581.	2.943	.143	170.0	52.3	36.9	3.94	4.17

```
                                        REGRESSION DATA FOR REGION IX

                               COLUMNS 13 - 23 ARE WATERSHED PARAMETERS

                  13      14      15        16       17       18       19       20      21      22       23
CASE      STA    %-FR    P-WB   %>6//     P-SCS     P-IN    S-IDX    L/R*S   19/A67  15/18S   8/10S   16/18S

  1 12-3005.   99.0    19.0     2.0      30.5     1.60    7.500     1.96    .083    .036    .334     .542
  2 12-3017.  100.0    22.0     1.0      31.0     1.50    7.500      .04    .036    .018    .434     .551
  3 12-3018.   99.4    22.0     4.0      29.2     1.50    7.500      .15    .045    .071    .342     .519
  4 12-3024.  100.0    21.0     1.0      40.0     1.60    6.400      .10    .090    .024    .178     .977
  5 12-3025.   88.8    22.0    32.0      76.5     1.90    5.900      .59    .071    .919    .267    2.198
  6 12-3035.   96.8    28.0    10.0      61.0     1.90    7.500     4.89    .136    .178    .278    1.084
  7 123042.5   97.7    19.0     1.0      45.0     1.60    7.500      .13    .068    .018    .272     .800
  8 12-3043.   96.5    19.0     4.0      56.0     1.60    7.000      .23    .071    .082    .218    1.143
  9 12-3044.   94.6    20.0     1.0      62.9     1.60    7.000      .23    .058    .020    .296    1.284
 10 12-3045.   98.0    21.0    23.0      43.0     1.70    7.500    11.33    .132    .409    .181     .764
 11 12-3550.   98.7    24.0    48.0      50.0     1.60    7.000     7.46    .124    .980    .255    1.020
 12 12-3555.   88.3    26.0    30.0      52.2     1.70    7.000    34.81    .254    .612    .158    1.065
 13 12-3560.   98.0    50.0    42.0      44.9     1.90    5.600      .30    .074   1.339    .277    1.432
 14 12-3570.   88.0    43.0    47.0      51.3     1.90    5.900     9.90    .152   1.350    .142    1.474
 15 12-3574.   80.0    30.0     1.0      38.0     1.80    6.000      .03    .118    .028    .278    1.056
 16 12-3575.   87.3    47.0    46.0      59.7     1.90    5.600    27.18    .276   1.467    .095    1.904
 17 12-3585.   85.7    48.0    45.0      61.4     1.90    5.900    29.88    .269   1.293    .108    1.764
 18 12-3590.   98.8    35.0    58.0      49.5     1.90    7.200    15.21    .153   1.119    .164     .955
 19 12-3600.   84.3    56.0    58.0      53.5     1.80    5.800     1.40    .106   1.724    .198    1.590
 20 12-3610.   81.0    35.0    39.0      58.5     1.90    6.000     1.17    .067   1.083    .422    1.625
 21 12-3615.   95.4    28.0    43.0      65.9     1.90    5.400      .50    .055   1.475    .333    2.260
 22 12-3625.   86.7    37.0    54.0      50.4     1.90    6.300    34.78    .242   1.361    .105    1.270
 23 12-3630.   87.7    38.0    40.0      53.5     1.80    5.600    40.36    .145   1.276    .338    1.706
 24 12-3660.   87.8    20.0    12.0      36.3     1.60    8.200     5.10    .163    .178    .125     .540
*EXIT*
```

APPENDIX B

FLOOD PREDICTION DATA AND METHODS
FOR
NATURAL WATERSHEDS

TABLE OF CONTENTS

PAGE

FLOOD PEAK PREDICTION EXAMPLES 1

GENERAL 1
Example 1 3
Example 2 4
Example 3 5
Example 4 6

FIELD DATA REQUIRED AT CULVERT SITE 9

FLOOD PEAK PREDICTION DATA 11-28

Fig. 1 Boundary locations for Flood Prediction Regions 11
Flood Peak Prediction Charts by Regions 12-23
Fig. 2 Montana 2-year 24-hour Precipitation Map 24
Fig. 3 SCS Mean Annual Precipitation Map 25
Table 1 Individual Exponent Prediction Equations for Various Recurrence Intervals 26
Table 2 Average Exponent Prediction Equations for Various Recurrence Intervals 28

FLOOD PEAK PREDICTION EXAMPLES

GENERAL

Adequate field data is needed so the office engineer may make the most economical culvert selection which will meet all design requirements at the site. The culvert installation should pass the design discharge within the limits of acceptable damage to the highway, the culvert installation, the natural drainage channel, and all upstream and downstream property.

The design discharge is predicted from charts or formulas applicable to the Flood Region in which the drainage area is located. Certain drainage area characteristics are used in this prediction. This discharge is described as having a certain recurrence interval T_p years, or probability of occurrence $P = 1/T_p$. For instance, the design discharge may be the so-called 50-year recurrence interval flood, Q_{50}. This does not mean that such a flood will occur once every 50 years, or that it will be 50 years before we may expect the flood to occur. A 50-year recurrence interval simply means that the probability is $P = 1/T_p = 1/50 = .02$ that a flood of equal or greater magnitude may occur in any year. The probability that such a flood may even occur two years in a row is not zero, but assuming annual flood events are independent of each other would be $.02^2 = .0004$. This is a small number, but it is not zero. The probability that such a flood will occur two or more times in 50 years if found from the binomial distribution[1] as .262 or about 1 in 4 or a 25% chance.

A recurrence interval of 50 years means that over a very long period of time, say X years (X = several hundred years) we would expect to find about X/50 different floods which equalled or exceeded Q_{50} in magnitude. In other words the 50 years is simply our best estimate of an average time period in a very long record.

The predicted discharge is the best estimate of the flood magnitude which has a given recurrence interval for the particular drainage area. In

---

[1] Benjamin and Cornell, Probability, Statistics, and Decision for Civil Engineers, McGraw-Hill Book Co., New York, 1970, p 232.

Flood Region there may be considerable variation in flood potential in different watersheds, even for drainage areas with essentially the same prediction equation characteristics. This should not be surprising since it was also true of the data from which the prediction equations were derived. For this reason it will be helpful if the field engineer indicates whether the drainage area is considered typical of the Flood Region in which it is located or whether it is expected to produce higher or lower flood magnitudes than are typical. This indication requires considerable insight into the hydrologic phenomena producing floods, and should only be made by experienced competent engineers. Another consideration which should not be overlooked is that watershed conditions in the predictable future may be of more interest than conditions in the past or even at present.

Fig. 1 shows the boundaries of the nine Flood Regions for which prediction equations were developed. These regions are designated I-IX and each is given a descriptive name indicating its location in Montana. Some drainage areas will be located near the border of a Flood Region. Although the prediction equations are different in each region, it is unreasonable to expect that flood magnitude will change abruptly from one Flood Region to another. For such areas therefore the field engineer should indicate which Flood Region best typifies the drainage area in question or how to weight flood estimates from each region to arrive at a reasonable estimate for the drainage area. The following discussion, which is concerned with illustrating various aspects of the flood prediction procedure, includes an example which illustrates the problem of making weighted flood estimates.

The procedure for determining design flood values from both the flood prediction charts and the prediction equations is illustrated by the following examples. Fig. 1 of this Appendix shows the Flood Region boundary locations while the individual and average exponent flood prediction equations are listed in Tables 1 and 2 respectively. The flood prediction charts, which provide a graphical solution to the average exponent equations, are also presented in this Appendix.

Example 1

Assume the design watershed is located near Lewistown, Montana in Flood Region II and has the following characteristics.

Drainage Area A = 10 sq mi

%>6000 = 21%

2-year 24-hour intensity I = 1.6 inch/24 hour (see 1969 ESSA map Fig. 2)

Estimate the 2-year and 50-year flood for this watershed using both the flood prediction chart and the individual exponent equations for Region II.

From the Region II Flood prediction Chart,

$$Q_2 = 53.0 \text{ cfs}$$

Since in Region II

$$Q_{50} = (6.18)(Q_2)$$
$$Q_{50} = (6.18)(53.0) = 328 \text{ cfs}$$

The individual exponent equations for Region II (see Table 1) are:

$$Q_2 = 5.48\ A^{.724}\ \%{>}6000^{-.162}\ I^{2.295}$$

$$Q_{50} = 83.5\ A^{.695}\ \%{>}6000^{-.427}\ I^{2.201}$$

Substituting the independent variable values into the above equations gives the following results:

$$Q_2 = 5.48(10)^{.724}\ (21)^{-.162}\ (1.6)^{2.29}$$

$$Q_2 = (5.48)(5.30)(1/1.64)(2.94) = 52.0 \text{ cfs}$$

and $$Q_{50} = 83.5(10)^{.695}\ (21)^{-.427}\ (1.6)^{2.201}$$

$$Q_{50} = (83.5)(4.95)(1/3.66)(2.83) = 319 \text{ cfs}$$

Example 2

As indicated in Tables 1 and 2 alternate equations are to be used in Regions III, V, and VIII depending on the magnitude of the F value for the design watershed. To illustrate consider a design watershed which is located in Region VIII. First estimate Q_{50} assuming the following independent variable values:

Drainage Area A = 25 sq mi
% Forest F = 80%
Mean Annual Precipitation PS = 31 in.

From the Region VIII Flood Prediction Chart for F > 16%

$$Q_2 = 140 \text{ cfs}$$

and

$$Q_{50} = (2.56)(140) = 358 \text{ cfs}$$

Likewise if the individual exponent equation is used:

$$Q_{50} = (243)(25)^{.940}\ (31)^{1.266}\ (80)^{-1.591}$$

$$Q_{50} = (243)(20.4)(77.6)(1/1010) = 382 \text{ cfs}$$

However, if the watershed had an F value less than 16%, say 10%, it becomes necessary to use the alternate prediction equations which do not include F as an independent variable.

From Tables 1 and 2 these are:

$$Q_{50} = (2.56)(.345)\ A^{.895}\ PS^{.909} \qquad \text{(average exponent)}$$
$$= (2.56)(.234)(25)^{.895}(31)^{.909} = 352 \text{ cfs}$$

and

$$Q_{50} = (2.55)\ A^{.871}\ PS^{.646} \qquad \text{(individual exponent)}$$
$$= (2.55)(25)^{.871}(31)^{.646} = 378 \text{ cfs}$$

As previously indicated when working with design watersheds in Regions III, V, and VIII, the proper set of flood prediction equations to be used will be determined by the magnitude of the F value for the watershed. If the value of F is below 19% and 16% for Regions III and VIII respectively then the set of alternate equations should be used. Likewise, if F exceeds 9% in Region V it is necessary to use the alternate equations. A flood prediction chart has been prepared for the Region V alternate equations, however the alternate equations for Regions III and VIII are solved manually as shown in this example, since Charts for them were not prepared.

Example 3

In Tables 1 and 2 it is seen that for Regions I and III the number of independent variables is not the same for all five recurrence interval equations. For example in Region III the 2 and 5 year equations contain the variables A, F and PS while the 10, 25 and 50 year equations contain only A and F. Similarly the 2, 5, 10 and 25 year Region I equations contain A and PS while the 50 year equations use only A. The flood prediction procedure for these two regions is now illustrated by finding the 2, 10 and 50 year flood peaks for a watershed in Region III using the following data.

Drainage Area A = 110 sq mi
% Forest F = 51%
Mean Annual Precipitation PS = 28 in

From the Region III Flood Prediction Chart for 2 and 5 year floods

Q_2 = 310 cfs

From the Region III Flood Prediction Chart for 10, 25, and 50 year floods:

$$Q_{10} = 480 \text{ cfs}$$

and since $Q_{50} = (1.47)Q_{10}$

$$Q_{50} = (1.47)(480) = 705 \text{ cfs}$$

Similarly, by use of the individual exponent prediction equations:

$$Q_2 = (.00172)A^{.970}\ F^{.758}\ PS^{1.39} = (.00172)(110)^{.970}\ (51)^{.758}\ (28)^{1.39}$$
$$= (.00172)(95.6)(19.5)(105) = 340 \text{ cfs}$$

$$Q_{10} = (.0793)A^{.911}\ F^{1.31} = (.0793)(110)^{.911}\ (51)^{1.131}$$
$$= (.0793)(72.6)(87.1) = 502 \text{ cfs}$$

$$Q_{50} = (.230)A^{.855}\ F^{1.023} = (2.30)(110)^{.855}\ (51)^{1.023}$$
$$= (.230)(56.1)(56.2) = 733 \text{ cfs}$$

Recall from Example 2 that Region III also has a set of alternate equations for use when F is less than 19%. However the same variables, namely A and PS, appear in all five of these alternate equations. Hence one is not concerned with using different variable combinations for different recurrence interval floods (as illustrated in this example) when using the Region III alternate equations.

Example 4

Consider now the problems associated with making flood predictions for a watershed located near the boundaries of two or more flood regions. Assume the watershed in question is located in Flood Region V but very close to the boundary between Region V and Region II.

Compute the design flood (Q_{50}) using the flood prediction charts for both Region V and II. The following watershed data apply:

Drainage Area A = 30 sq mi
% Forest F = 8%
%>6000 = 19%
2 year-24 hour intensity I = 1.8 inch/24 hour

From the Region II Flood Prediction Chart

$$Q_2 = 160 \text{ cfs}$$

$$Q_{50} = (6.18)(Q_2) = (6.18)(160) = 990 \text{ cfs}$$

From the Region V Flood Prediction Chart

$$Q_2 = 55 \text{ cfs}$$

$$Q_{50} = (6.65)(55) = 365 \text{ cfs}$$

It is obvious that the above estimates of Q_2 and Q_{50} differ greatly in magnitude. Because of this a detailed analysis of the design watershed is needed to determine if either of these Q_{50} values is a preferred estimate best or how the two values should be weighted to give the most reasonable result. However, assuming that such detailed information is not available, the designer could arrive at a compromise between the two Q_{50} values by simply averaging them.

Thus

$$Q_{50} = \frac{990 + 365}{2} = \frac{1455}{2} = 727 \text{ cfs} \qquad \text{(simple average)}$$

To illustrate a more refined procedure, assume that the field engineer has indicated that, according to his judgment, about 70% of the watershed is typical of characteristics common to Region V and about

30% is representative of conditions found in Region II. This type of information can be used to make a weighted prediction of the design flood.

The weighted prediction would be,

$$\begin{aligned} Q_{50} &= (.3)(990) + .70(365) \\ &= 297 + 256 = 553 \text{ cfs} \end{aligned}$$

FIELD DATA REQUIRED AT CULVERT SITES

The following specific information should be gathered at each culvert site:

A. Drainage Area

1. Size, accurate to about 5%
2. Describe general soil, cover, and topographic characteristics.
3. Evaluate all watershed characteristics needed in prediction equations, or refer for office evaluation.

B. Natural Drainage Channel

1. Is stream flow perennial or intermittent?
2. Describe stream channel at flood stage so that a Manning n value may be estimated (See Table 2, Appendix D). Indicate bed and bank material, including size, extent of curvature, extent of bank caving, amount of weeds and brush in channel and on banks, etc.
3. Obtain channel profiles for at least 500 ft both upstream and downstream to define channel slope. Such profiles should include any significant changes in slope or elevation which exist.
4. For well defined channels, obtain at least 3 X-sections, one upstream, one downstream, and one at the culvert site to define water cross section at flood stage.
5. Record any high water elevations obtainable. Record size of openings for any culverts or other waterways in stream channel in the near vicinity.
6. Record elevation of and describe any irrigation structures, croplands, roadways, buildings, or other features subject to flooding due to backwater which may be produced by the culvert, to aid in establishing the maximum allowable headwater.
7. Describe any protection required at culvert outlet and in downstream channel to insure a stable channel with acceptable erosion. What estimated maximum velocity will the stream channel safely carry? What estimated maximum velocity has the stream channel carried in the past? Describe the basis of both of these estimated velocities.

8. Record data describing any channel constrictions or obstruction downstream from the culvert site.
9. Describe debris problems at site, if they exist. Are trash racks required?
10. Describe any anticipated problems caused by ice at the site, or ice which may be carried to the site during spring break-ups.

C. Describe and document any other conditions or features at the culvert site, of which the office engineer should be aware.

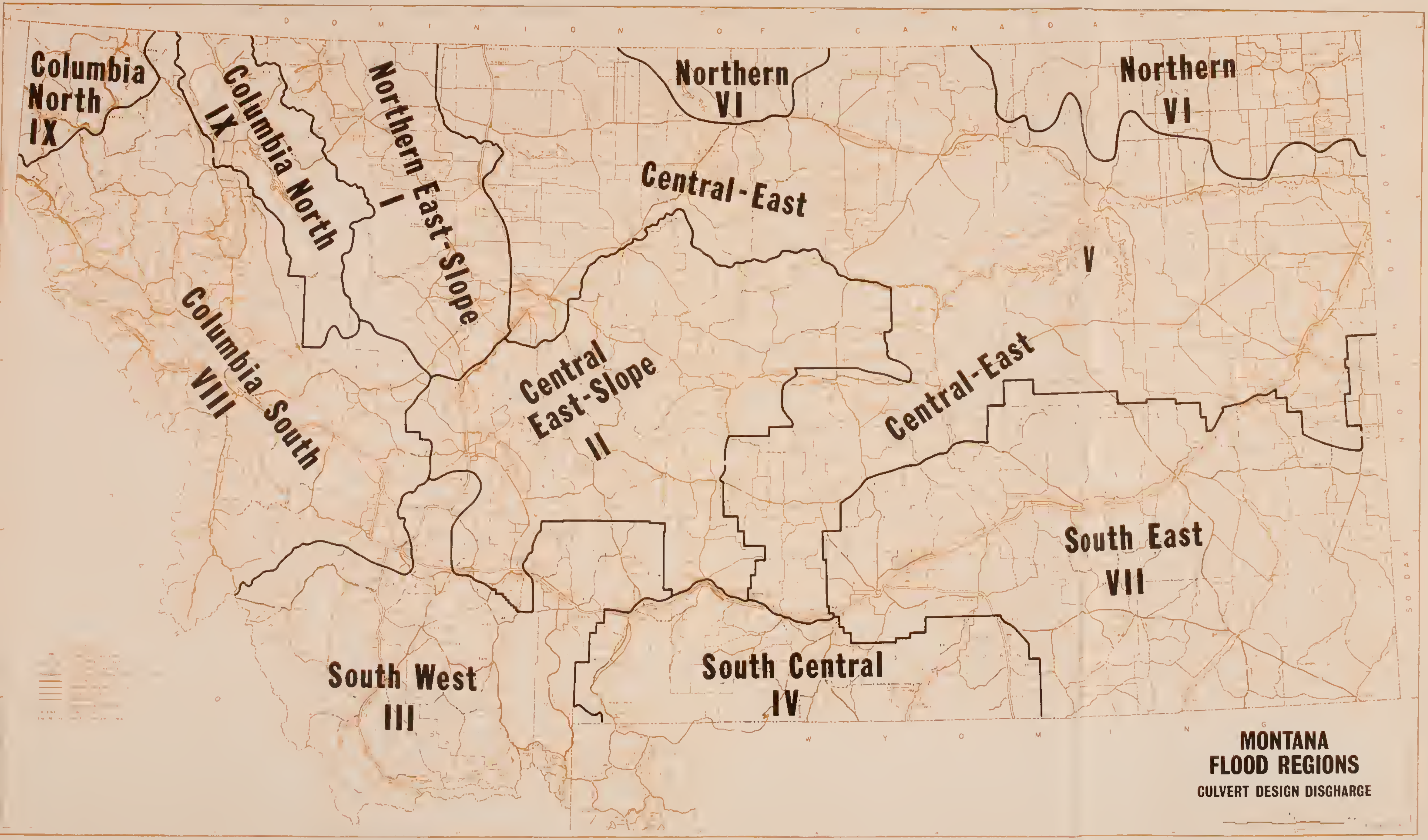
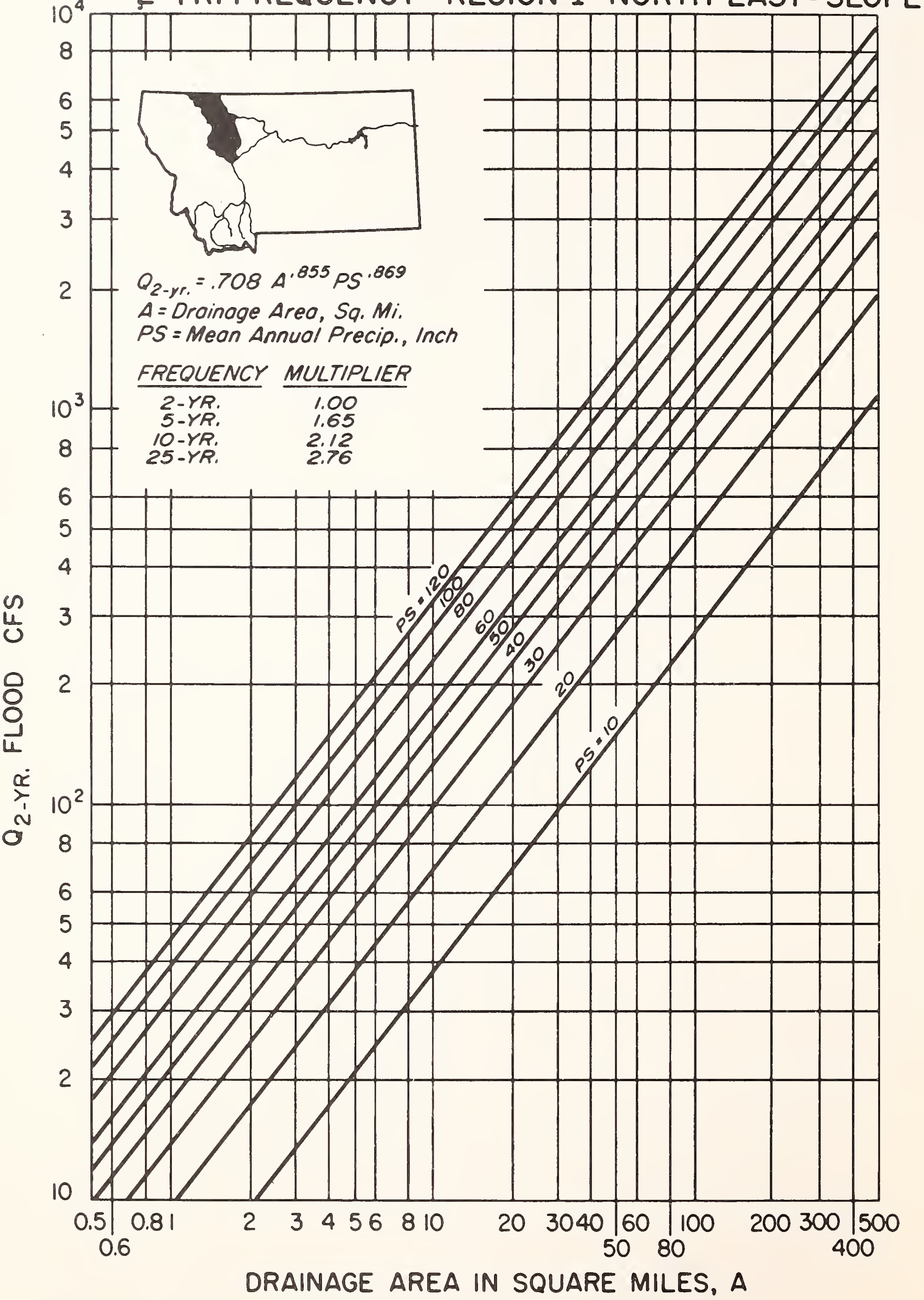

DOMINION OF CANADA
Columbia North IX
Columbia North IX
Northern East-Slope I
Northern VI
Northern VI
Central-East
V
Central East-Slope II
Central-East
Columbia South VIII
South East VII
South West III
South Central IV
WYOMING
NORTH DAKOTA
SOUTH DAKOTA
MONTANA
FLOOD REGIONS
CULVERT DESIGN DISCHARGE

Fig 1

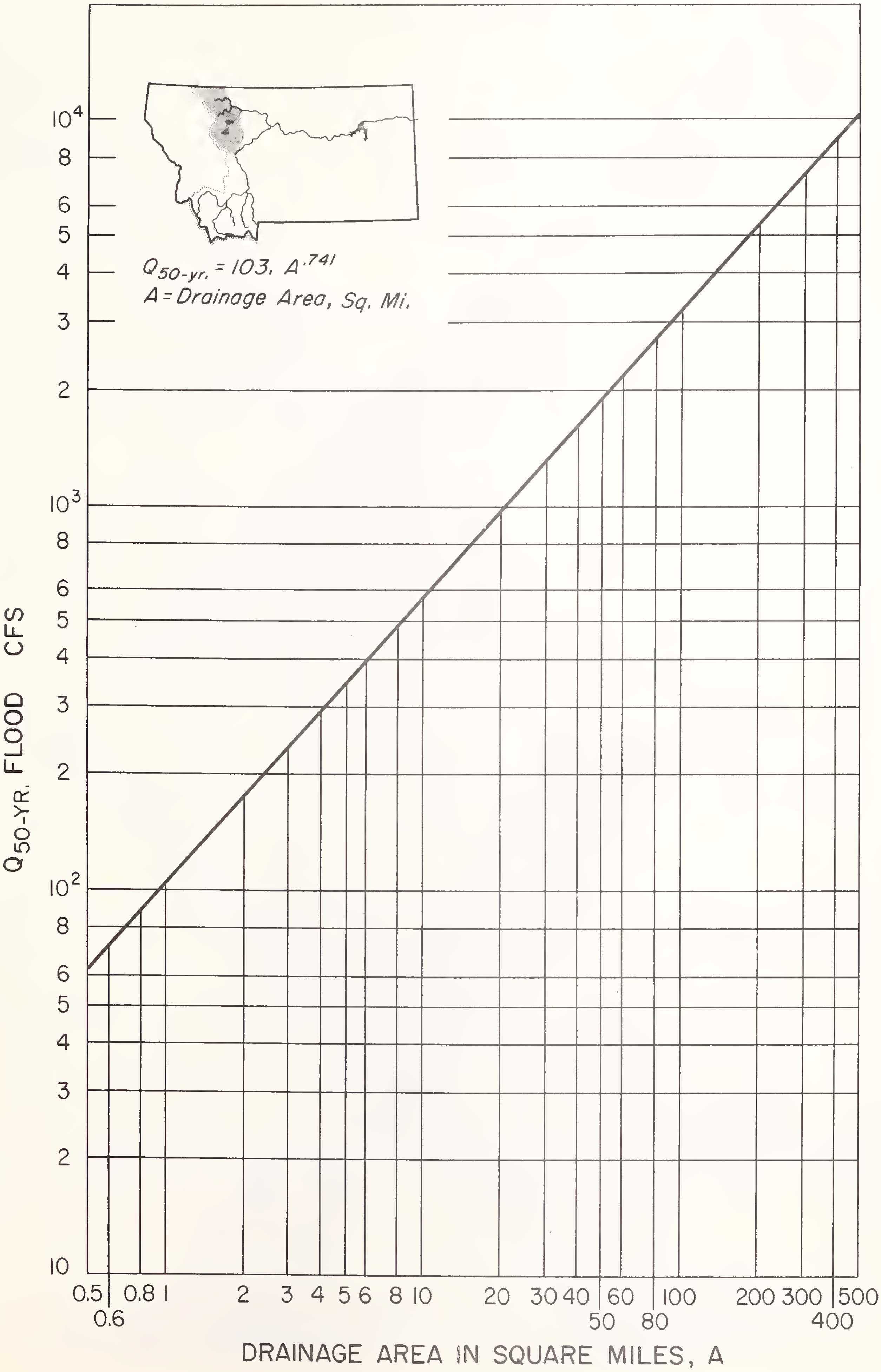
MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION I NORTH EAST-SLOPE



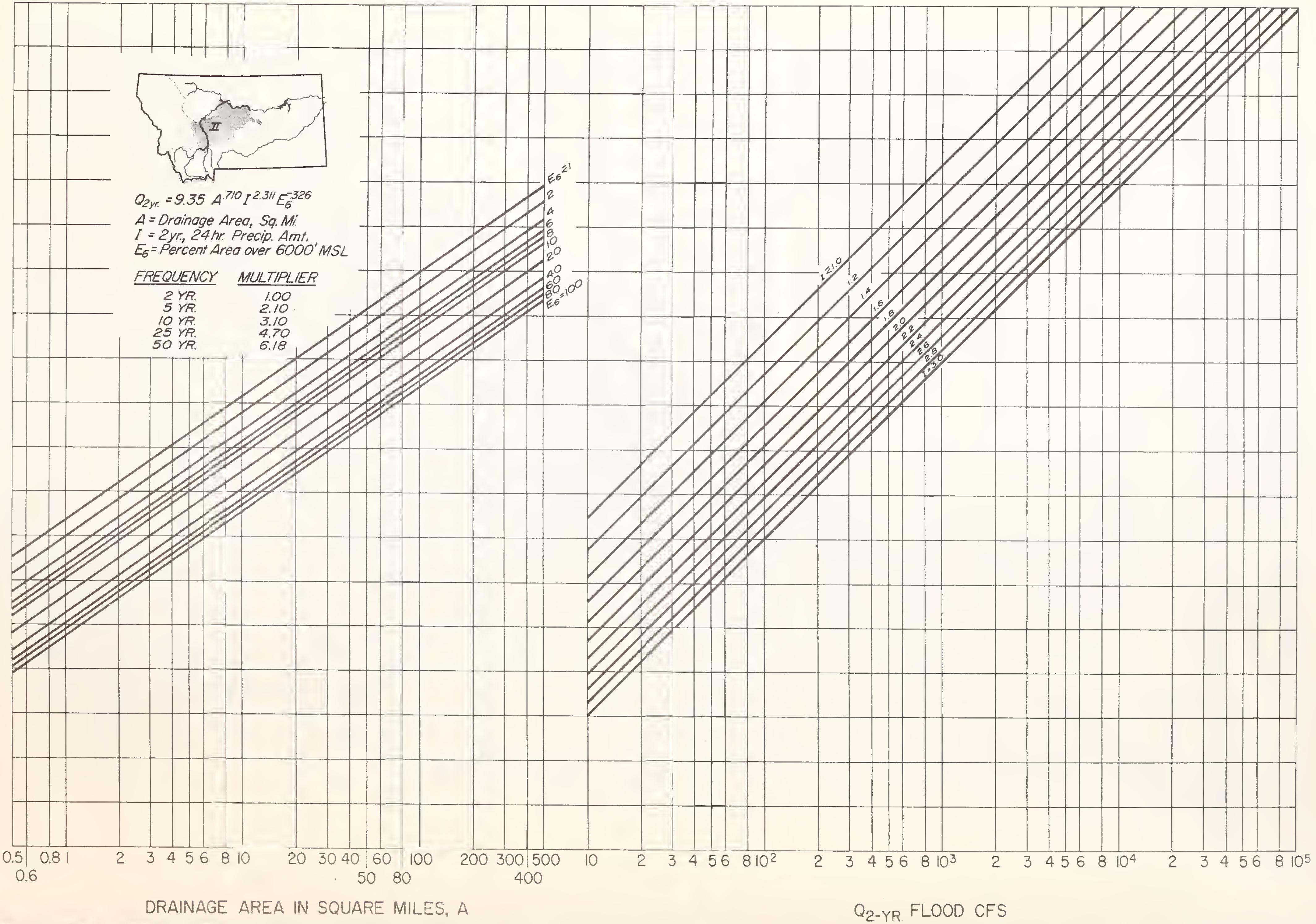
MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

50-YR. FREQUENCY REGION I NORTH EAST-SLOPE



MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION II CENTRAL EAST-SLOPE



$Q_{2yr.} = 9.35\ A^{.710}\ I^{2.311}\ E_6^{-.326}$

A = Drainage Area, Sq. Mi.

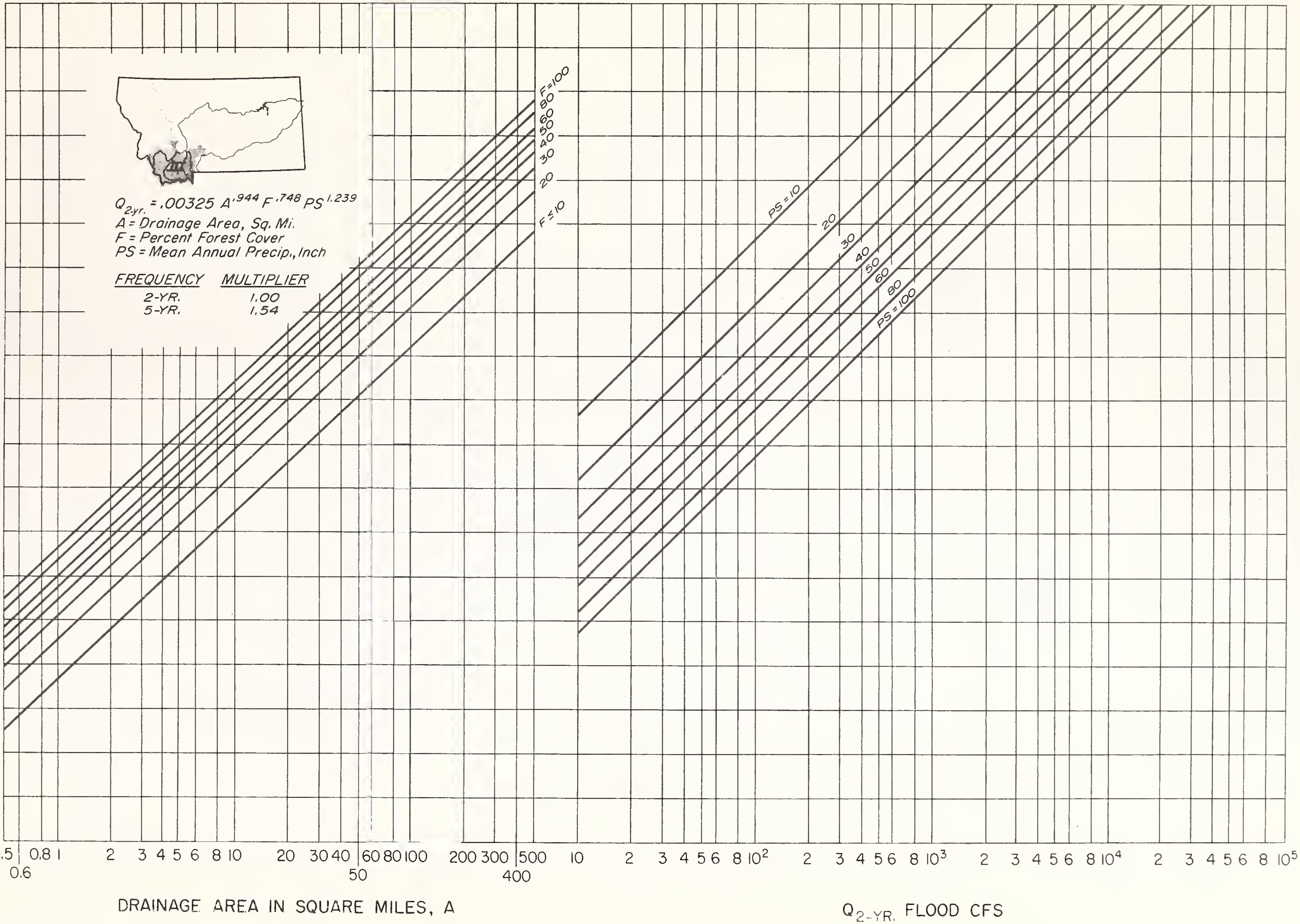
I = 2yr., 24 hr. Precip. Amt.

E_6 = Percent Area over 6000' MSL

FREQUENCY	MULTIPLIER
2 YR.	1.00
5 YR.	2.10
10 YR.	3.10
25 YR.	4.70
50 YR.	6.18

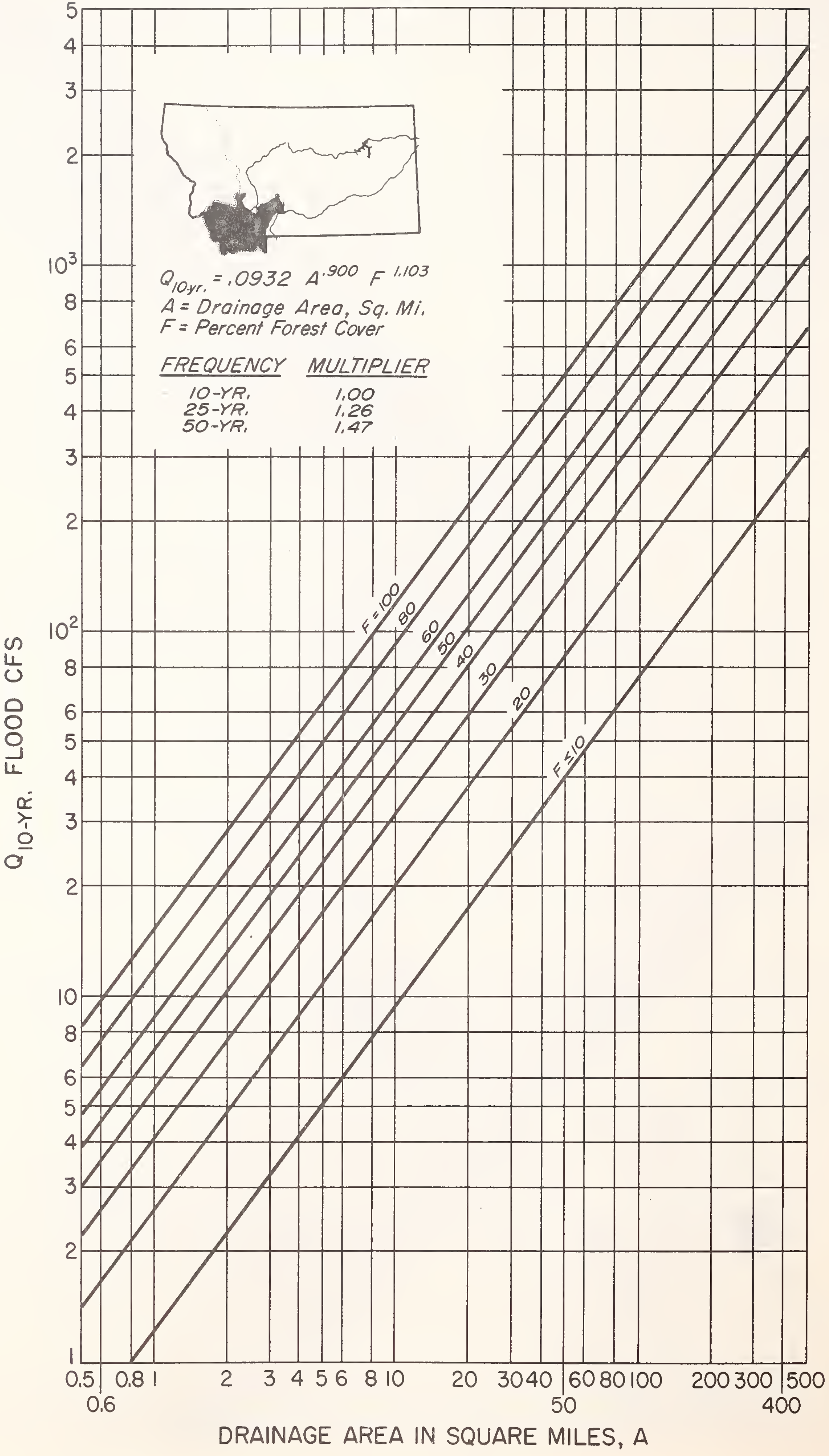
MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION III SOUTHWEST



MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

10-YR. FREQUENCY REGION III SOUTHWEST

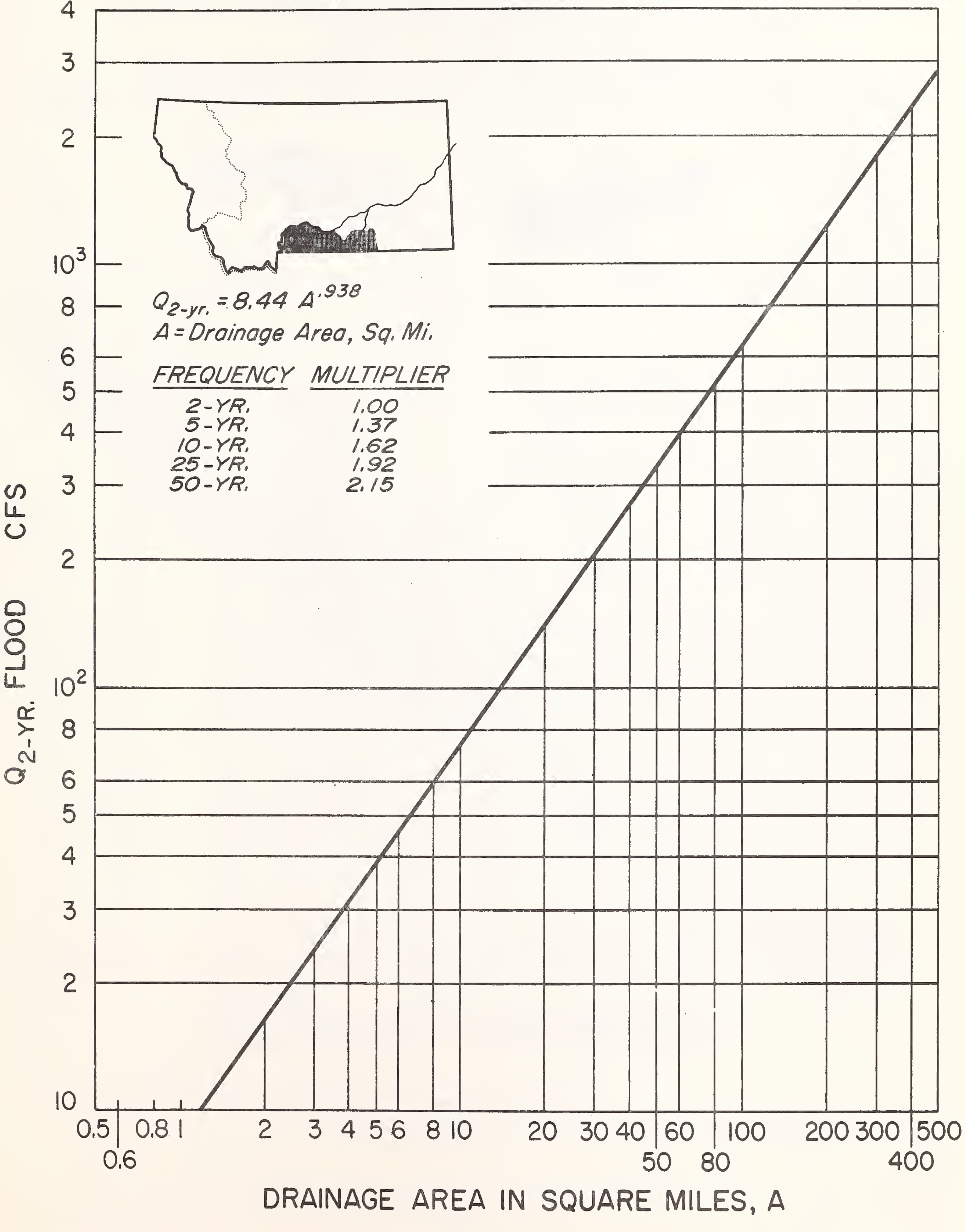


$Q_{10\text{-yr.}} = .0932\ A^{.900}\ F^{1.103}$

A = Drainage Area, Sq. Mi.
F = Percent Forest Cover

FREQUENCY	MULTIPLIER
10-YR.	1.00
25-YR.	1.26
50-YR.	1.47

MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE
2-YR. FREQUENCY REGION IV SOUTH CENTRAL



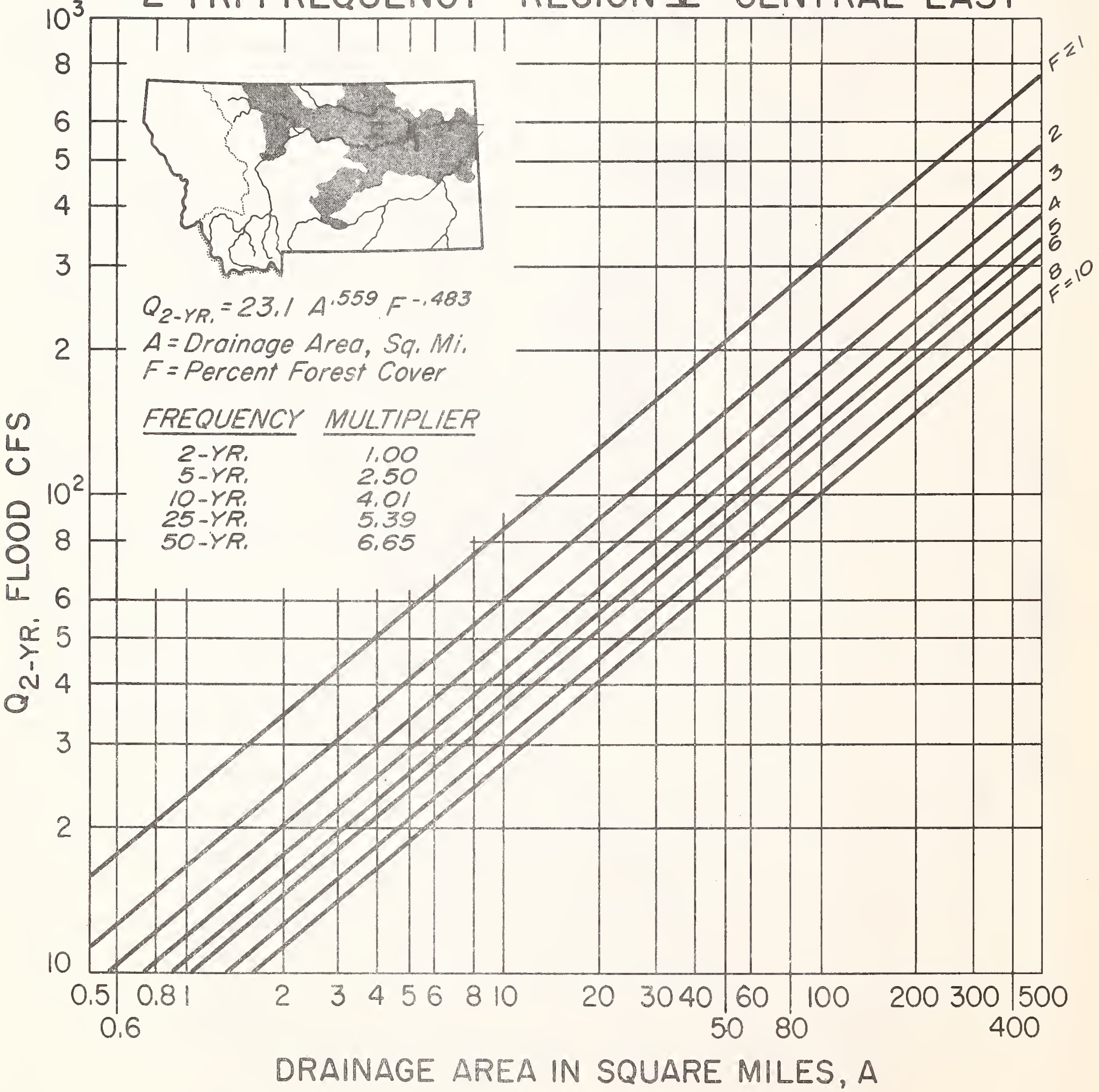
$Q_{2\text{-yr.}} = 8.44\ A^{.938}$

A = Drainage Area, Sq. Mi.

FREQUENCY	MULTIPLIER
2-YR.	1.00
5-YR.	1.37
10-YR.	1.62
25-YR.	1.92
50-YR.	2.15

MONTANA HIGHWAY DEPARTMENT CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION V* CENTRAL-EAST



$Q_{2\text{-YR.}} = 23.1\ A^{.559}\ F^{-.483}$

A = Drainage Area, Sq. Mi.

F = Percent Forest Cover

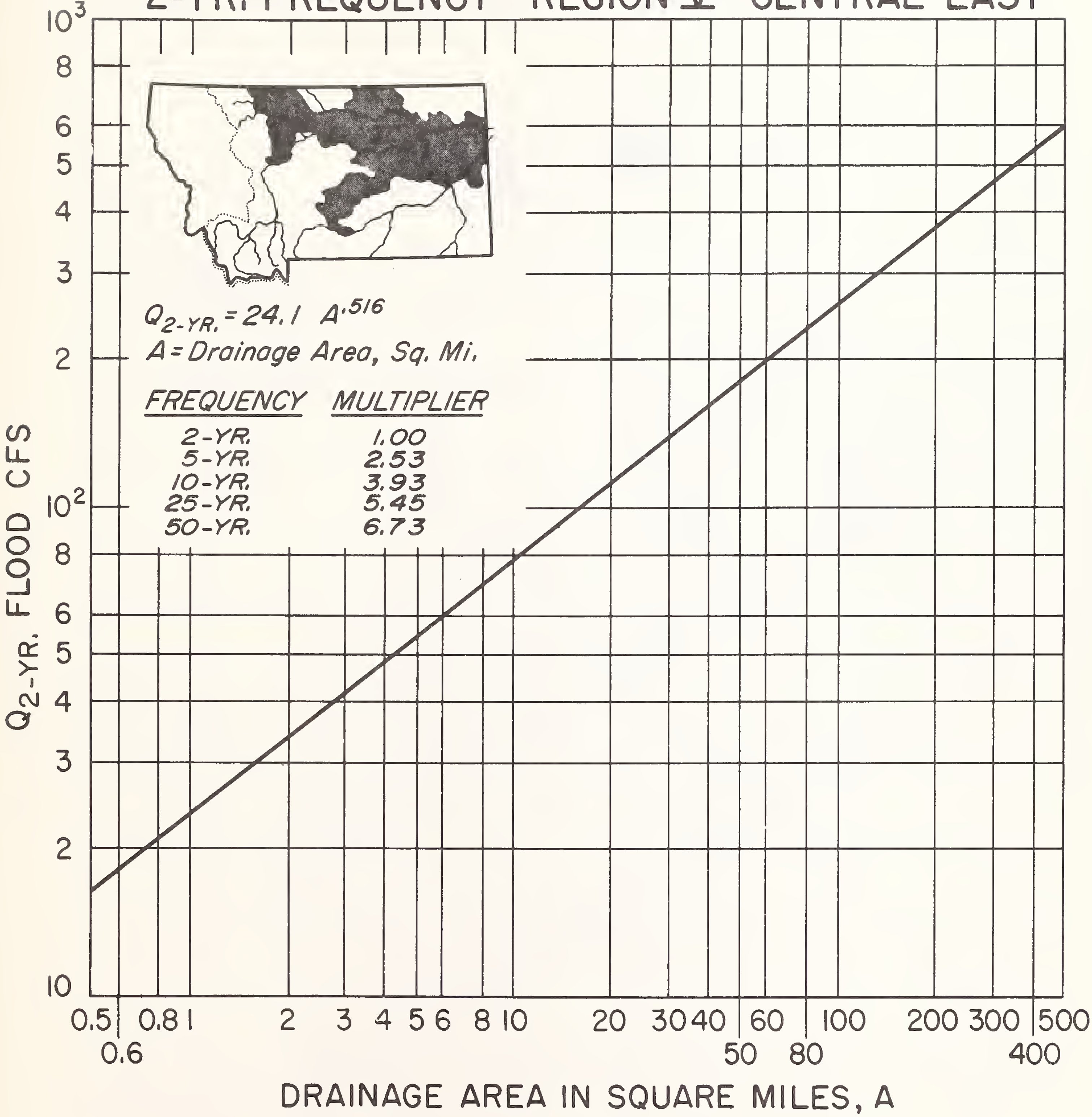
FREQUENCY	MULTIPLIER
2-YR.	1.00
5-YR.	2.50
10-YR.	4.01
25-YR.	5.39
50-YR.	6.65

---

*Use this chart only if % forest is less than 9%

MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION V* CENTRAL-EAST



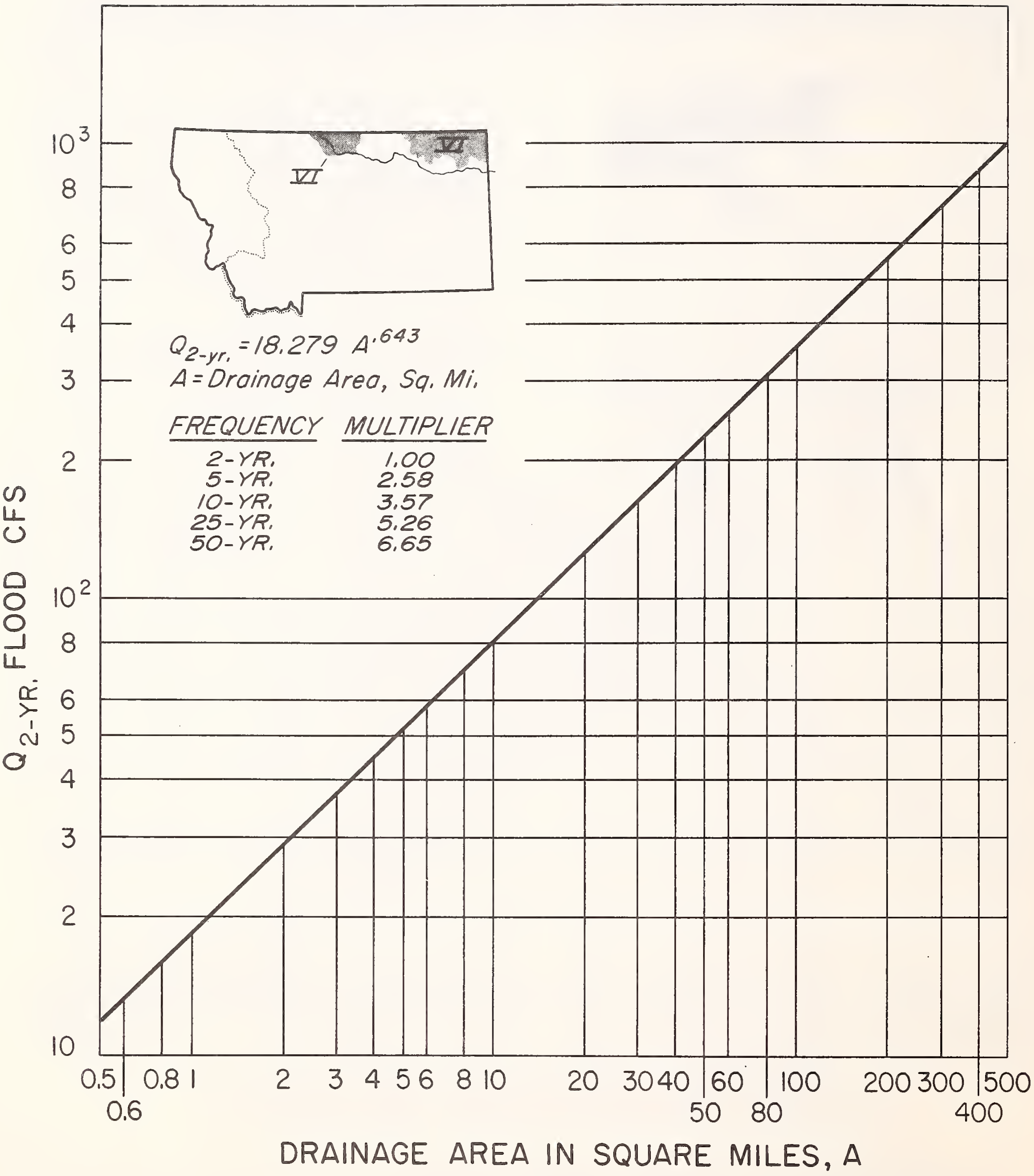
$Q_{2\text{-}YR.} = 24.1\ A^{.516}$

A = Drainage Area, Sq. Mi.

FREQUENCY	MULTIPLIER
2-YR.	1.00
5-YR.	2.53
10-YR.	3.93
25-YR.	5.45
50-YR.	6.73

*Use this chart only if % forest is greater than 9%

MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE
2-YR. FREQUENCY REGION VI NORTHERN

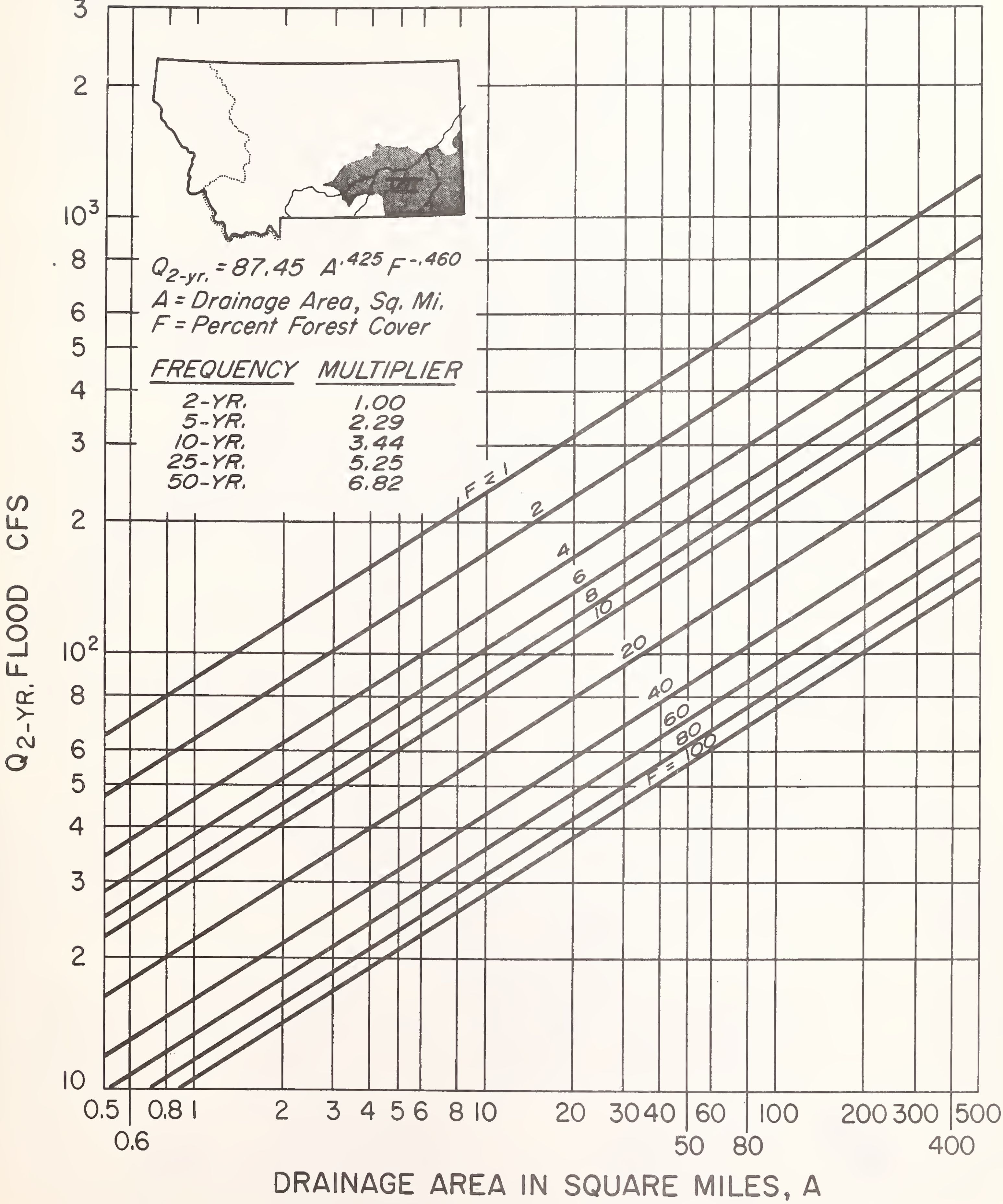


$Q_{2\text{-yr.}} = 18.279\ A^{.643}$

A = Drainage Area, Sq. Mi.

FREQUENCY	MULTIPLIER
2-YR.	1.00
5-YR.	2.58
10-YR.	3.57
25-YR.	5.26
50-YR.	6.65

MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE
2-YR. FREQUENCY REGION VII SOUTHEAST



$Q_{2\text{-yr.}} = 87.45\ A^{.425}\ F^{-.460}$

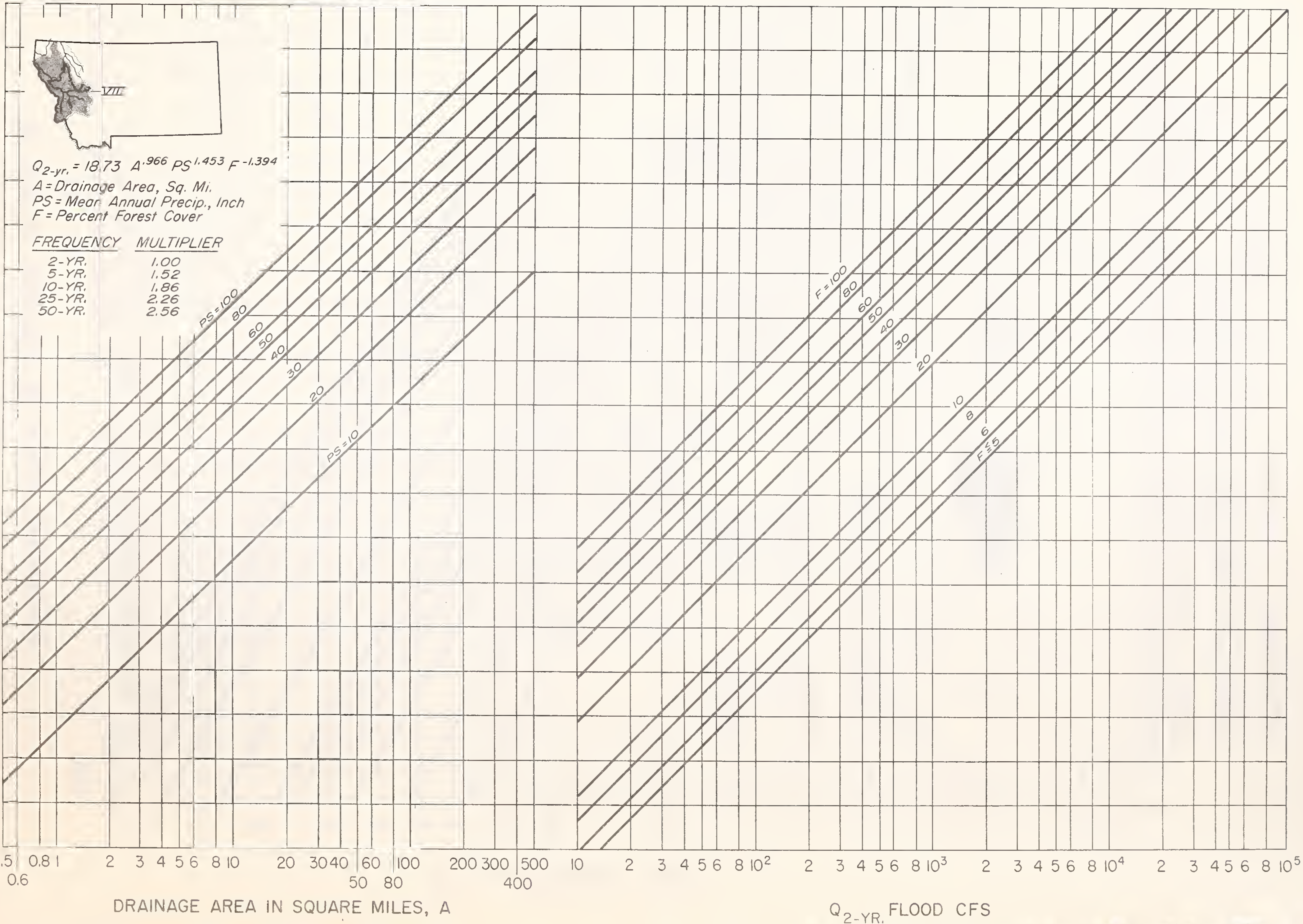
A = Drainage Area, Sq. Mi.

F = Percent Forest Cover

FREQUENCY	MULTIPLIER
2-YR.	1.00
5-YR.	2.29
10-YR.	3.44
25-YR.	5.25
50-YR.	6.82

MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION VIII COLUMBIA-SOUTH



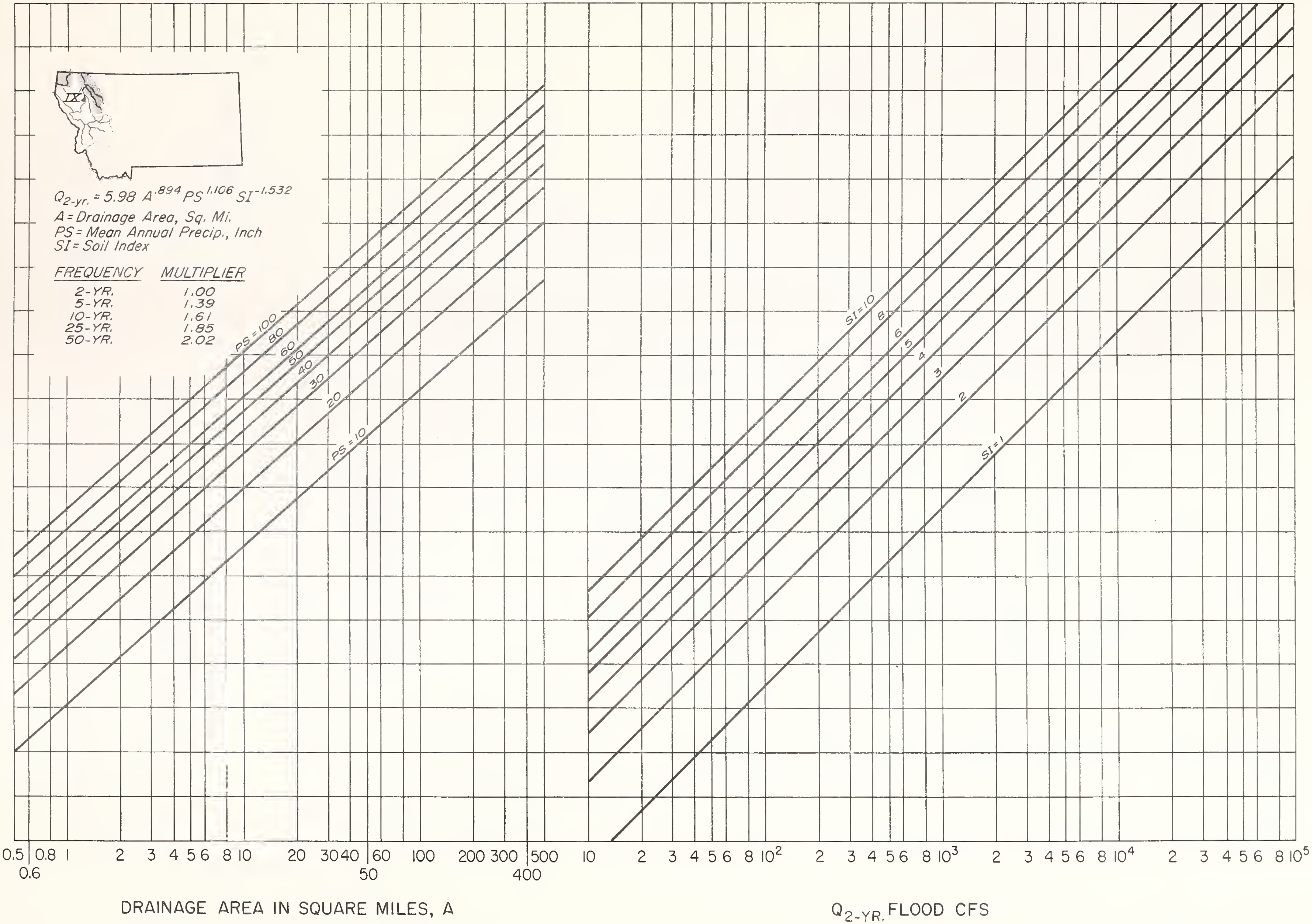
$Q_{2\text{-yr.}} = 18.73\ A^{.966}\ PS^{1.453}\ F^{-1.394}$

A = Drainage Area, Sq. Mi.
PS = Mean Annual Precip., Inch
F = Percent Forest Cover

FREQUENCY	MULTIPLIER
2-YR.	1.00
5-YR.	1.52
10-YR.	1.86
25-YR.	2.26
50-YR.	2.56

MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

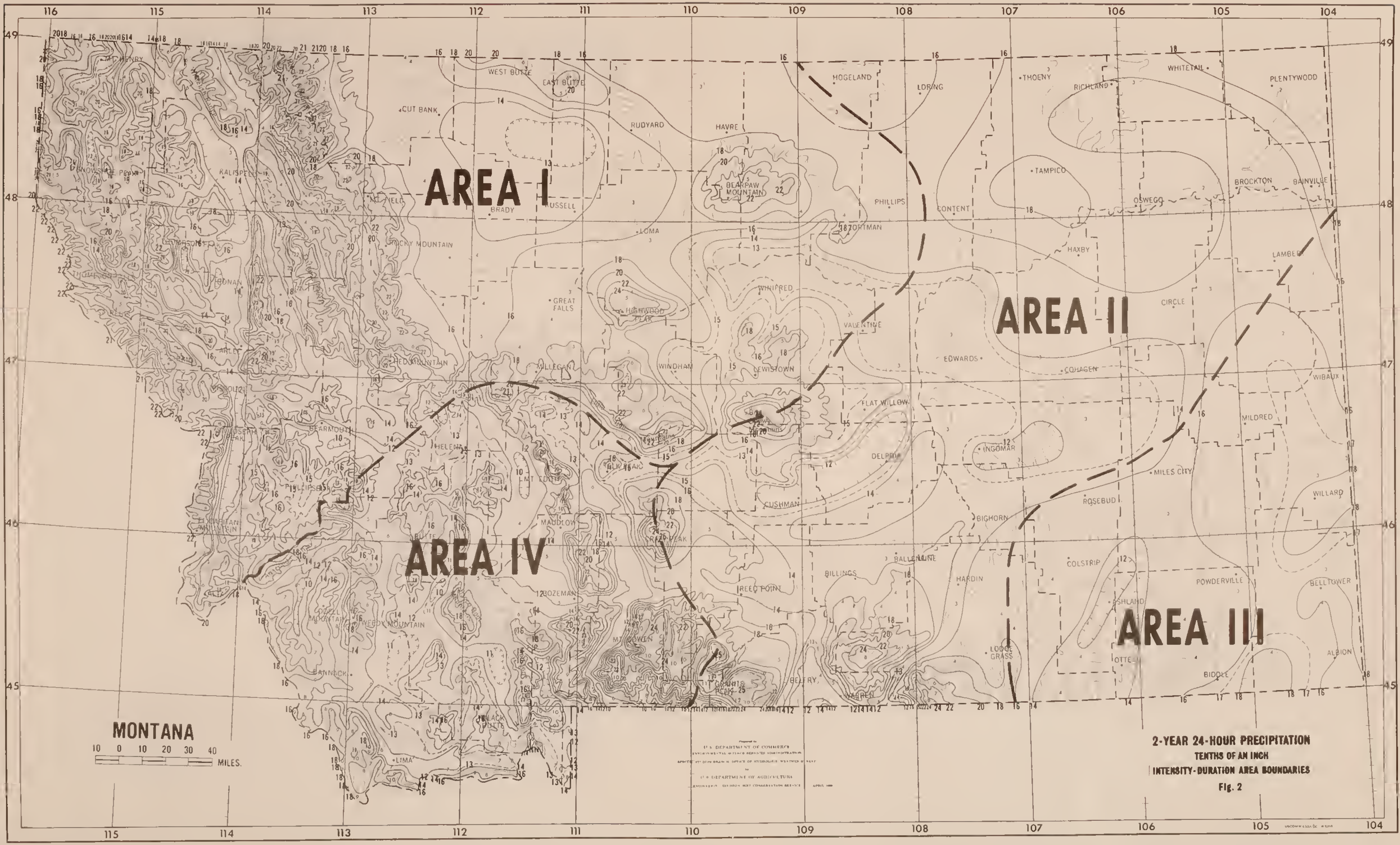
2-YR. FREQUENCY REGION IX COLUMBIA-NORTH



$Q_{2\text{-yr.}} = 5.98\, A^{.894}\, PS^{1.106}\, SI^{-1.532}$

A = Drainage Area, Sq. Mi.
PS = Mean Annual Precip., Inch
SI = Soil Index

FREQUENCY	MULTIPLIER
2-YR.	1.00
5-YR.	1.39
10-YR.	1.61
25-YR.	1.85
50-YR.	2.02



2-YEAR 24-HOUR PRECIPITATION
TENTHS OF AN INCH
INTENSITY-DURATION AREA BOUNDARIES
Fig. 2

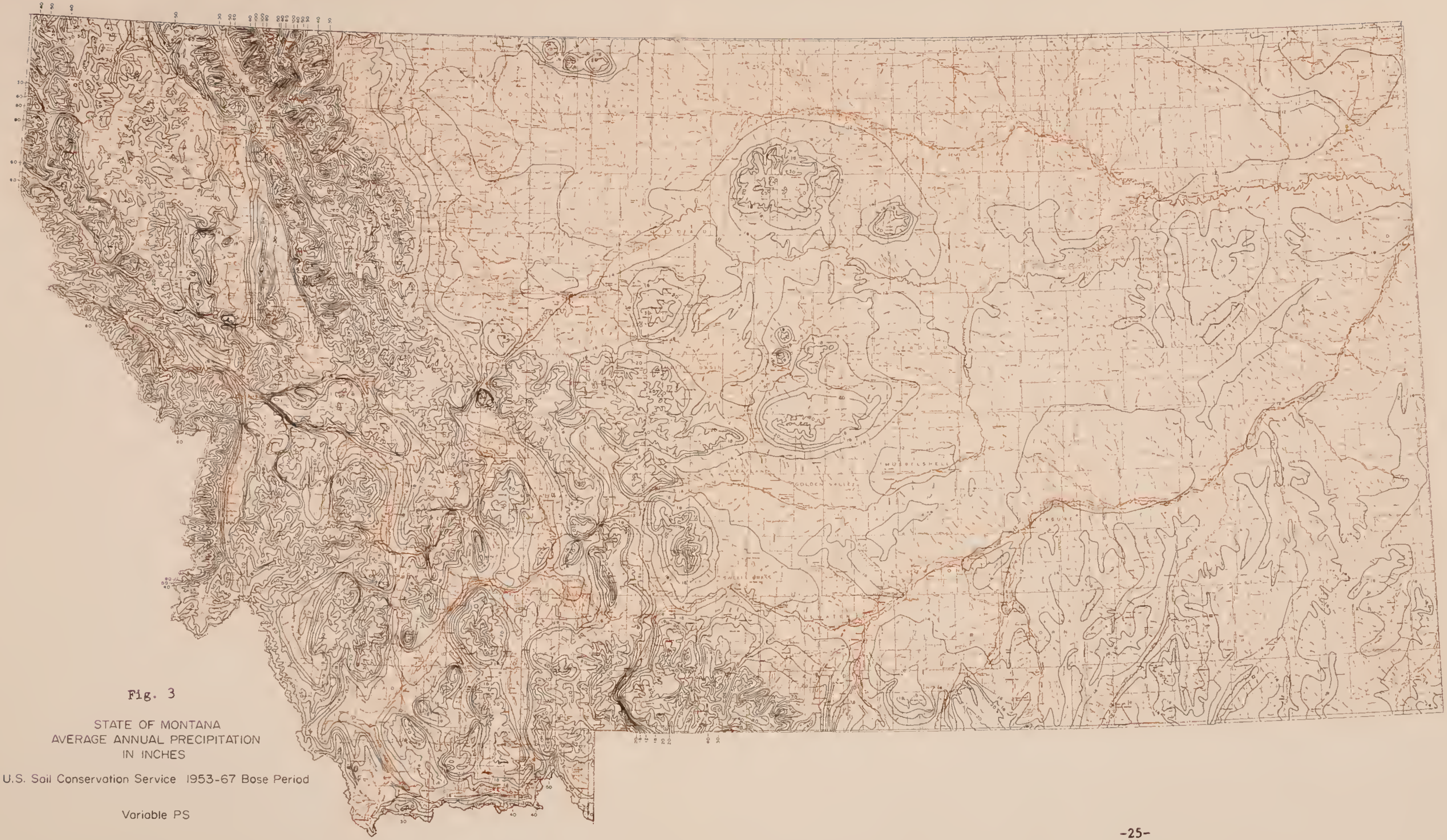


Fig. 3

STATE OF MONTANA
AVERAGE ANNUAL PRECIPITATION
IN INCHES

U.S. Soil Conservation Service 1953-67 Base Period

Variable PS

TABLE 1

Prediction Equations for Various Recurrence Intervals

$$Q_1 = b_o X_1^{b_1} X_2^{b_2} \ldots X_n^{b_n}$$

(Individual Exponent Equations)

--Exponents $b_1 \ldots b_n$ for above variables[1] --

REGION I

Flood	Regression Constant b_o	A	PS	F	SI	%>6000	I
Q_2	.0673	.920	1.414				
Q_5	.839	.862	.948				
Q_{10}	3.195	.834	.695				
Q_{25}	13.40	.805	.419				
Q_{50}	103.1	.741					

REGION II

Flood	Regression Constant b_o	A	PS	F	SI	%>6000	I
Q_2	5.483	.724				-.162	2.295
Q_5	16.41	.716				-.293	2.406
Q_{10}	29.31	.709				-.347	2.371
Q_{25}	55.08	.703				-.400	2.284
Q_{50}	83.56	.695				-.427	2.201

REGION III
For % Forest > 19%

Flood	Regression Constant b_o	A	PS	F	SI	%>6000	I
Q_2	.00172	.970	1.390	.758			
Q_5	.00944	.919	1.087	.738			
Q_{10}	.0793	.911		1.131			
Q_{25}	.1549	.877		1.061			
Q_{50}	.2301	.855		1.023			

Alternate Equations if Forest is < 19%

Flood	Regression Constant b_o	A	PS	F	SI	%>6000	I
Q_2	.00356	.918	2.203				
Q_5	.190	.869	1.879				
Q_{10}	.0450	.843	1.715				
Q_{25}	.115	.811	1.536				
Q_{50}	.207	.791	1.427				

REGION IV

Flood	Regression Constant b_o	A	PS	F	SI	%>6000	I
Q_2	4.57	1.045					
Q_5	9.46	.973					
Q_{10}	14.13	.932					
Q_{25}	21.98	.885					
Q_{50}	29.44	.854					

---

[1] See Table 8 for meaning of variable designations

TABLE 1 (cont.)

Flood	Regression Constant b_o	A	PS	F	SI	%>6000	I
		--Exponents b_1 ... b_n for above variables--					
REGION V For Forest < 9%							
Q_2	27.04	.510		-.428			
Q_5	60.26	.547		-.471			
Q_{10}	84.62	.565		-.490			
Q_{25}	116.1	.581		-.508			
Q_{50}	138.8	.591		-.519			
Alternate if % Forest > 9%							
Q_2	28.18	.472					
Q_5	62.97	.506					
Q_{10}	88.72	.521					
Q_{25}	122.0	.536					
Q_{50}	146.0	.545					
REGION VI							
Q_2	14.89	.663					
Q_5	42.07	.634					
Q_{10}	59.16	.642					
Q_{25}	87.50	.638					
Q_{50}	109.6	.636					
REGION VII							
Q_2	69.75	.484		-.434			
Q_5	188.8	.443		-.461			
Q_{10}	308.3	.421		-.467			
Q_{25}	509.3	.397		-.469			
Q_{50}	696.6	.382		-.469			
REGION VIII For % Forest > 16%							
Q_2	2.415	1.00	1.708	-1.168			
Q_5	14.32	.975	1.528	-1.307			
Q_{10}	38.46	.961	1.433	-1.398			
Q_{25}	116.9	.948	1.331	-1.509			
Q_{50}	243.8	.940	1.266	-1.591			
Alternate if Forest < 16%							
Q_2	.0852	.945	1.25				
Q_5	.344	.908	1.02				
Q_{10}	.700	.890	.888				
Q_{25}	1.54	.871	.742				
Q_{50}	2.55	.859	.646				
REGION IX							
Q_2	1.064	.937	1.284		-1.099		
Q_5	5.133	.900	1.145		-1.397		
Q_{10}	10.23	.888	1.095		-1.560		
Q_{25}	23.28	.876	1.023		-1.754		
Q_{50}	38.39	.869	.982		-1.880		

TABLE 2

Prediction Equations for Various Recurrence Intervals

$$Q_{\overline{R}_i} = b_i X_1^{\overline{b}_1} X_2^{\overline{b}_2} X_3^{\overline{b}_3}$$

(Average Exponent Equations)

Flood	Regression Constant b_i	A	PS	F	SI	%>6000	I
		Exponents $\overline{b}_1, \overline{b}_2 \dots \overline{b}_n$ for above variables					
REGION I							
Q_2	.7078	.855	.869				
Q_5	1.165	.855	.869				
Q_{10}	1.500	.855	.869				
Q_{25}	1.953	.855	.869				
Q_{50}	103.0	.7414					

$Q_5 = 1.65\ Q_2$ $Q_{10} = 2.12\ Q_2$ $Q_{25} = 2.76\ Q_2$

Flood	Regression Constant b_i	A	PS	F	SI	%>6000	I
REGION II							
Q_2	9.354	.710				-.326	2.311
Q_5	19.655	.710				-.326	2.311
Q_{10}	29.031	.710				-.326	2.311
Q_{25}	43.948	.710				-.326	2.311
Q_{50}	57.769	.710				-3.26	2.311

$Q_5 = 2.10\ Q_2$ $Q_{10} = 3.10\ Q_2$ $Q_{25} = 4.70\ Q_2$ $Q_{50} = 6.18\ Q_2$

REGION III
For % Forest > 19%

Flood	Regression Constant b_i	A	PS	F	SI	%>6000	I
Q_2	.00325	.944	1.239	.748			
Q_5	.00500	.944	1.239	.748			
Q_{10}	.0932	.900		1.103			
Q_{25}	.1178	.900		1.103			
Q_{50}	.1367	.900		1.103			

$Q_5 = 1.54\ Q_2$ $Q_{25} = 1.25\ Q_{10}$ $Q_{50} = 1.47\ Q_{10}$

Alternate if % Forest < 19%

Flood	Regression Constant b_i	A	PS	F	SI	%>6000	I
Q_2	.00432	.846	1.752				
Q_5	.00662	.846	1.752				
Q_{10}	.00829	.846	1.752				
Q_{25}	.0105	.846	1.752				
Q_{50}	.0121	.846	1.752				

$Q_5 = 1.53\ Q_2$ $Q_{10} = 1.92\ Q_2$ $Q_{25} = 2.43\ Q_2$ $Q_{50} = 2.81\ Q_2$

TABLE 2 (cont.)

Flood	Regression Constant b_i	A	PS	F	SI	%>6000	I
		Exponents $\bar{b}_1$, $\bar{b}_2$, ... $\bar{b}_n$ for above variables					
		REGION IV					
Q_2	8.455	.938					
Q_5	11.596	.938					
Q_{10}	13.667	.938					
Q_{25}	16.272	.938					
Q_{50}	18.209	.938					
$Q_5 = 1.37\ Q_2$		$Q_{10} = 1.62\ Q_2$			$Q_{25} = 1.92\ Q_2$		$Q_{50} = 2.15\ Q_2$
		REGION V For % Forest < 9%					
Q_2	23.102	.559		-.483			
Q_5	57.978	.559		-.483			
Q_{10}	92.663	.559		-.483			
Q_{25}	124.776	.559		-.483			
Q_{50}	154.017	.559		-.483			
$Q_5 = 2.50\ Q_2$		$Q_{10} = 4.01\ Q_2$			$Q_{25} = 5.39\ Q_2$		$Q_{50} = 6.65\ Q_2$
		Alternate if % Forest > 9%					
Q_2	24.074	.5161					
Q_5	60.775	.5161					
Q_{10}	90.442	.5161					
Q_{25}	130.796	.5161					
Q_{50}	161.461	.5161					
$Q_5 = 2.52\ Q_2$		$Q_{10} = 3.75\ Q_2$			$Q_{25} = 5.41\ Q_2$		$Q_{50} = 6.69\ Q_2$
		REGION VI					
Q_2	18.279	.643					
Q_5	47.340	.643					
Q_{10}	65.501	.643					
Q_{25}	96.250	.643					
Q_{50}	121.591	.643					
$Q_5 = 2.58\ Q_2$		$Q_{10} = 3.57\ Q_2$			$Q_{25} = 5.26\ Q_2$		$Q_{50} = 6.65\ Q_2$
		REGION VII					
Q_2	87.451	.425		-.460			
Q_5	200.343	.425		-.460			
Q_{10}	301.692	.425		-.460			
Q_{25}	458.716	.425		-.460			
Q_{50}	595.528	.425		-.460			
$Q_5 = 2.29\ Q_2$		$Q_{10} = 3.44\ Q_2$			$Q_{25} = 5.25\ Q_2$		$Q_{50} = 6.82\ Q_2$

TABLE 2 (cont.)

Flood	Regression Constant b_i	A	PS	F	SI	%>6000	I
		Exponents $\bar{b}_1, \bar{b}_2, \ldots \bar{b}_n$ for above variables					

REGION VIII
For % Forest > 16%

Q_2	18.728	.966	1.453	-1.394			
Q_5	28.421	.966	1.453	-1.394			
Q_{10}	34.706	.966	1.453	-1.394			
Q_{25}	42.437	.966	1.453	-1.394			
Q_{50}	47.957	.966	1.453	-1.394			

$Q_5 = 1.52\ Q_2$ $Q_{10} = 1.86\ Q_2$ $Q_{25} = 2.26\ Q_2$ $Q_{50} = 2.56\ Q_2$

Alternate if % Forest < 16%

Q_2	.345	.895	.909				
Q_5	.523	.895	.909				
Q_{10}	.639	.895	.909				
Q_{25}	.781	.895	.909				
Q_{50}	.883	.895	.909				

$Q_5 = 1.5\ Q_2$ $Q_{10} = 1.85\ Q_2$ $Q_{25} = 2.27\ Q_2$ $Q_{50} = 2.56\ Q_2$

REGION IX

Q_2	5.977	.894	1.106		-1.532		
Q_5	8.340	.894	1.106		-1.532		
Q_{10}	9.633	.894	1.106		-1.532		
Q_{25}	11.068	.894	1.106		-1.532		
Q_{50}	12.036	.894	1.106		-1.532		

$Q_5 = 1.39\ Q_2$ $Q_{10} = 1.61\ Q_2$ $Q_{25} = 1.85\ Q_2$ $Q_{50} = 2.02\ Q_2$

APPENDIX C

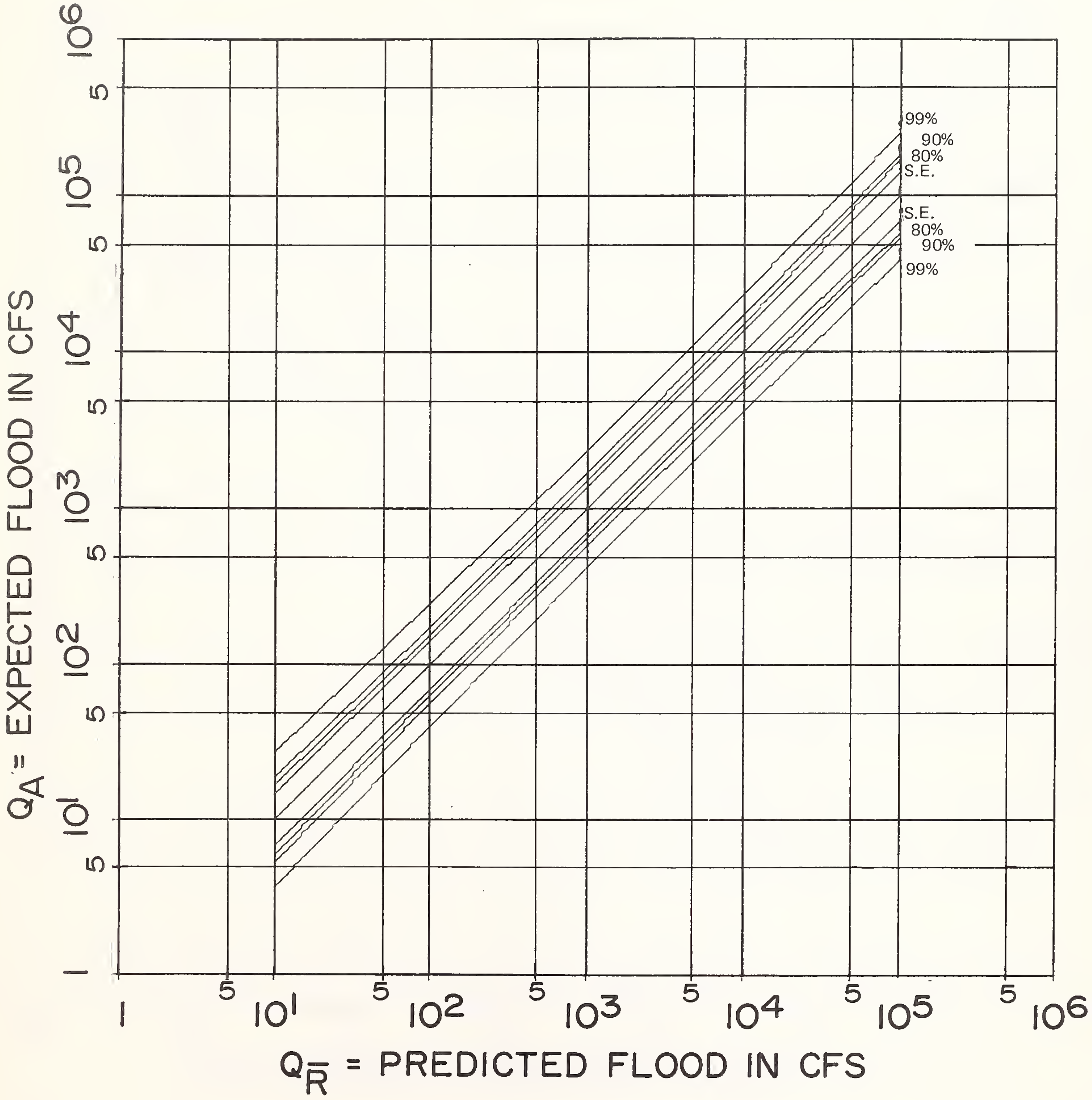
CONFIDENCE INTERVAL CHARTS FOR NINE FLOOD REGIONS FOR AVERAGE EXPONENT REGRESSION EQUATIONS

TABLE OF CONTENTS

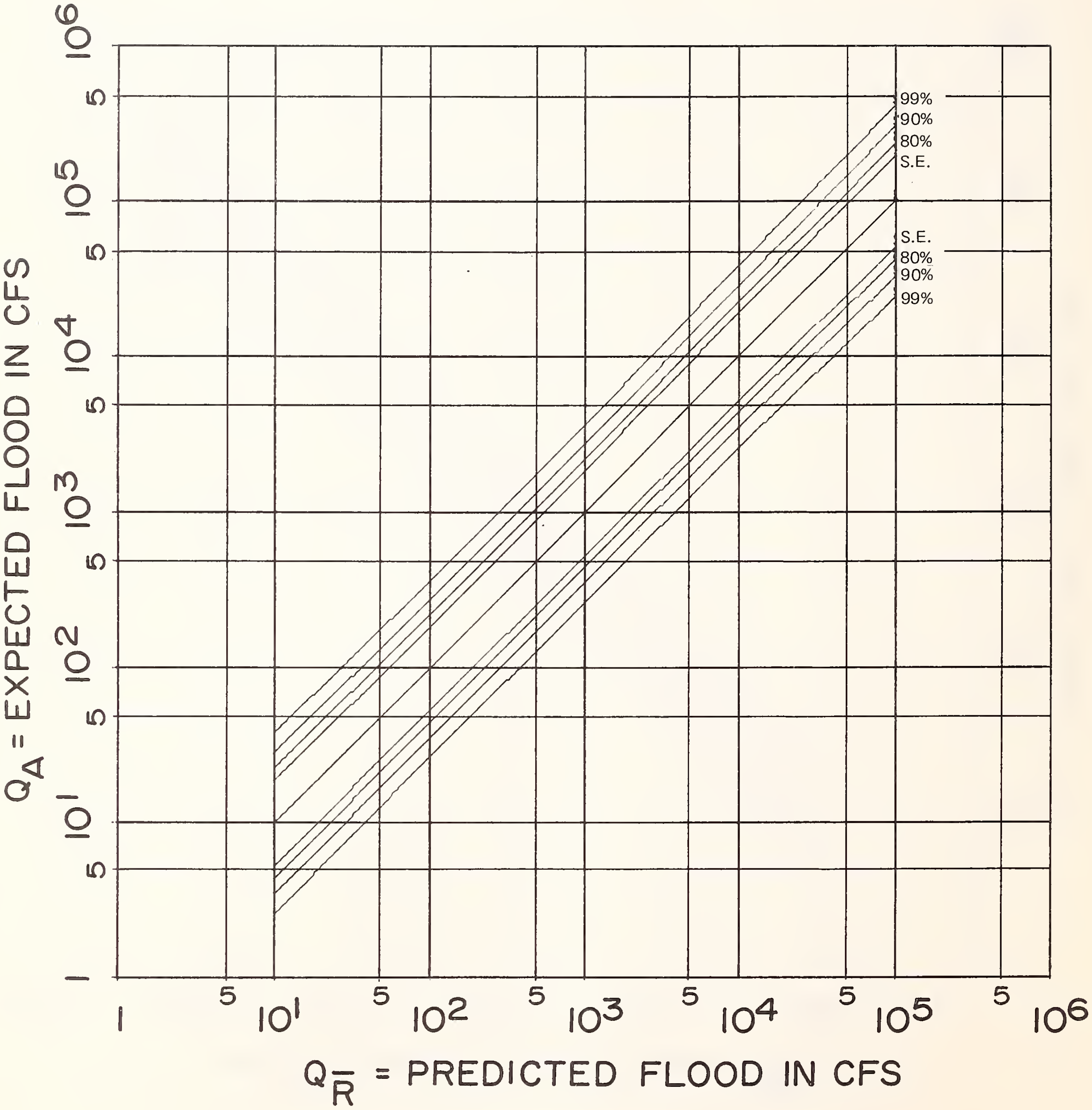
Page

CONFIDENCE INTERVAL CHARTS (AVERAGE EXPONENT EQUATIONS)

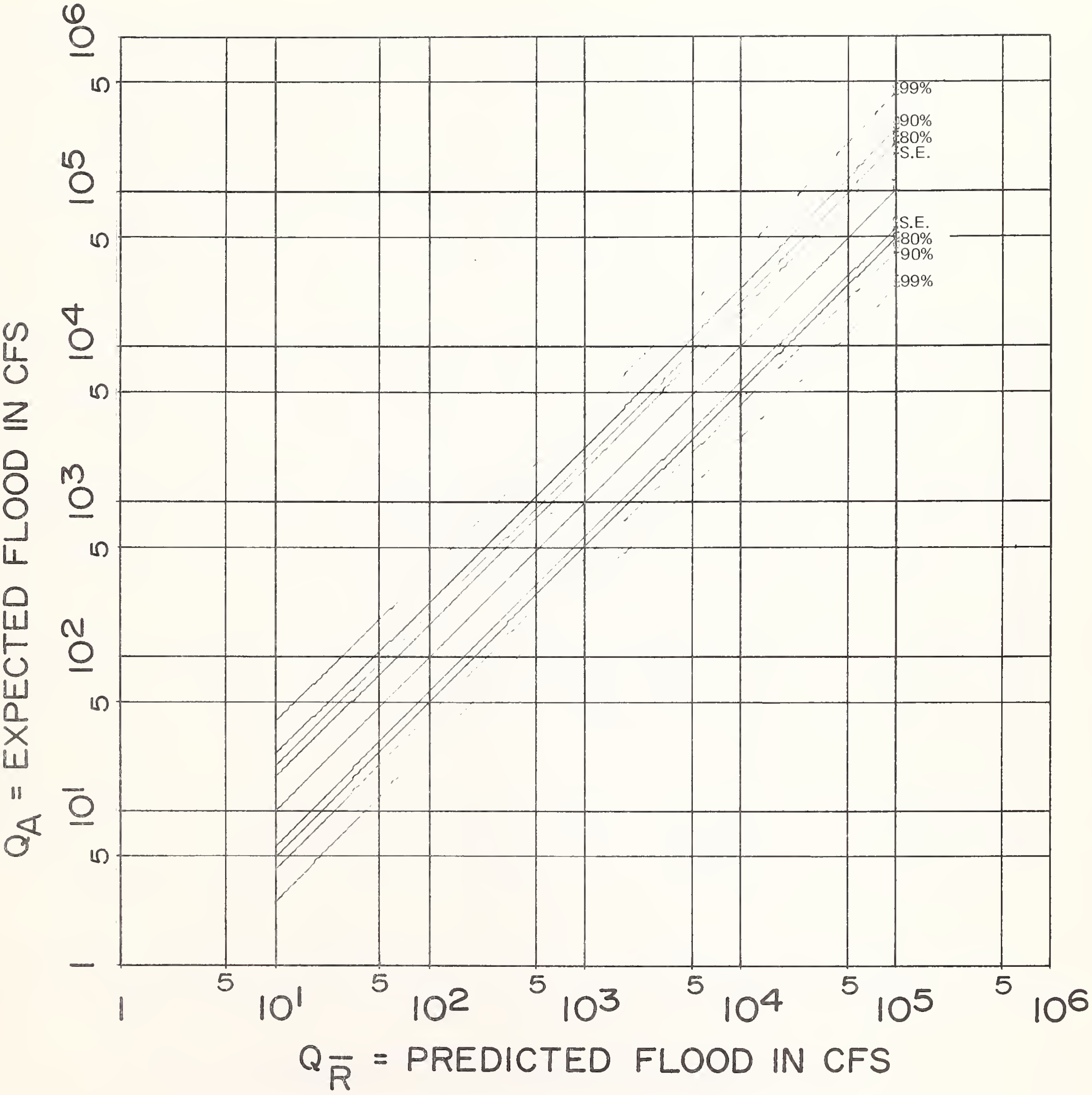
REGION I 1
REGION II 2
REGION III 3
REGION IV 4
REGION V 5
REGION VI 6
REGION VII 7
REGION VIII 8
REGION IX 9



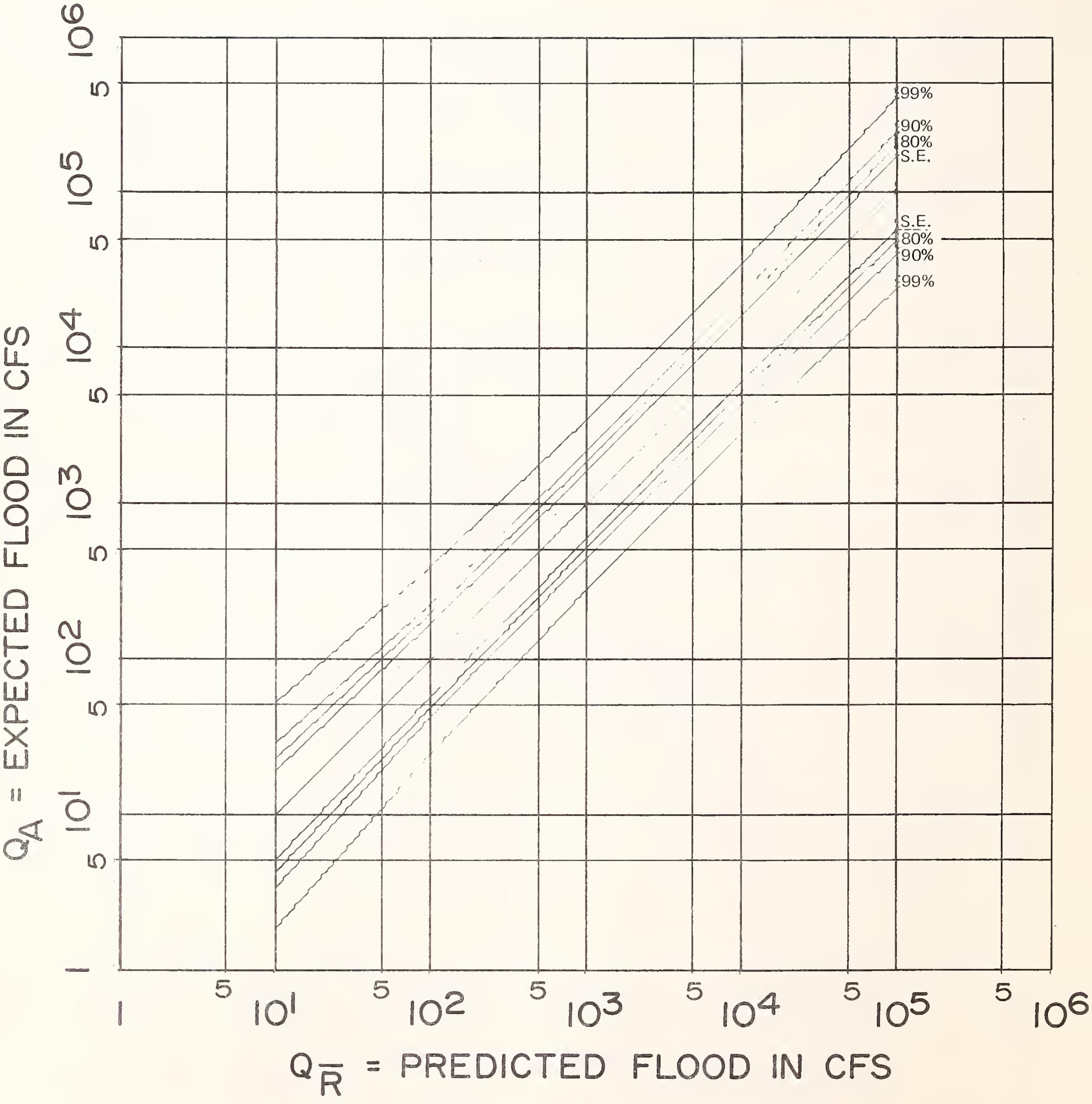
CONFIDENCE INTERVALS FOR REGION I



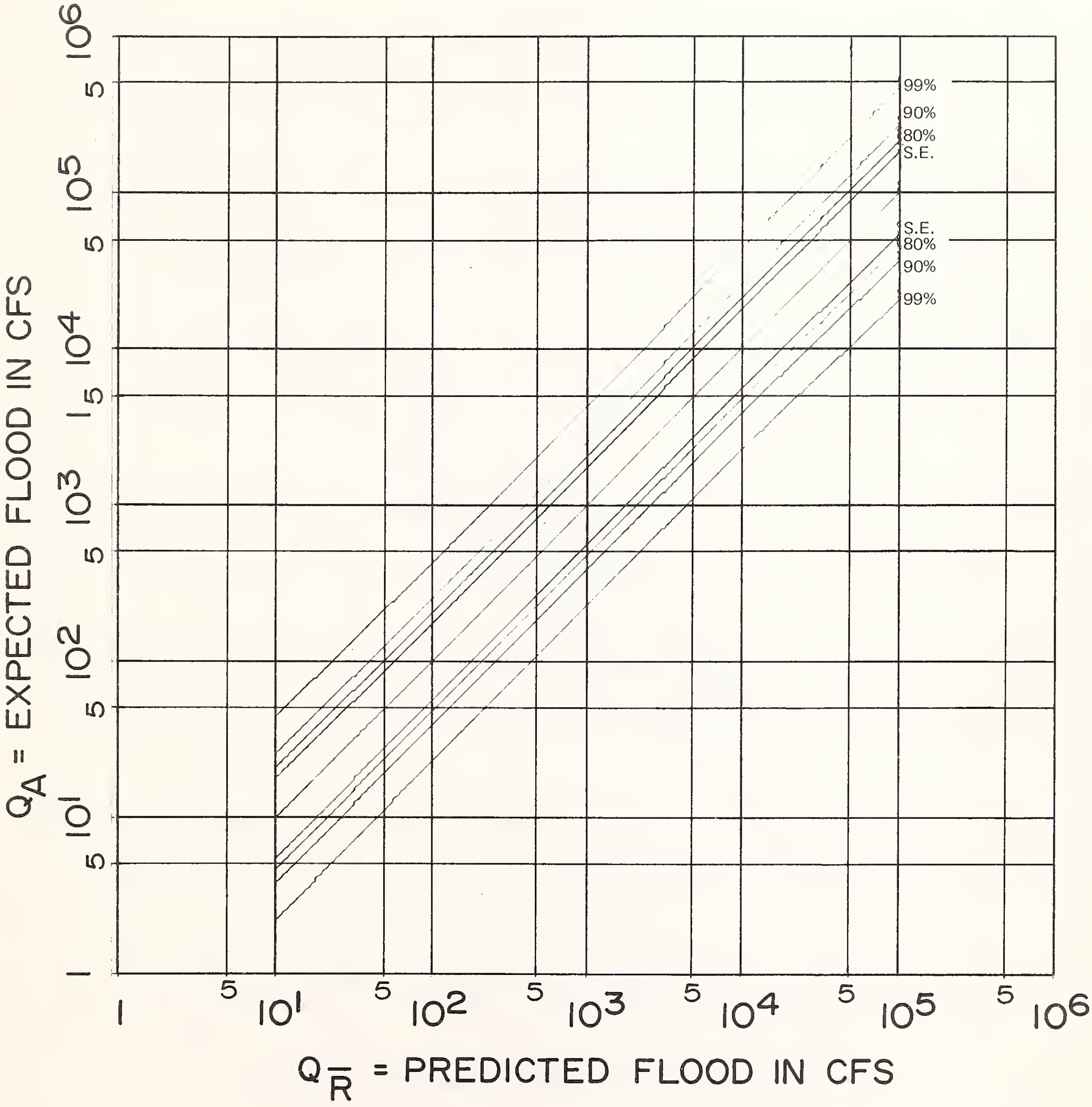
CONFIDENCE INTERVALS FOR REGION II



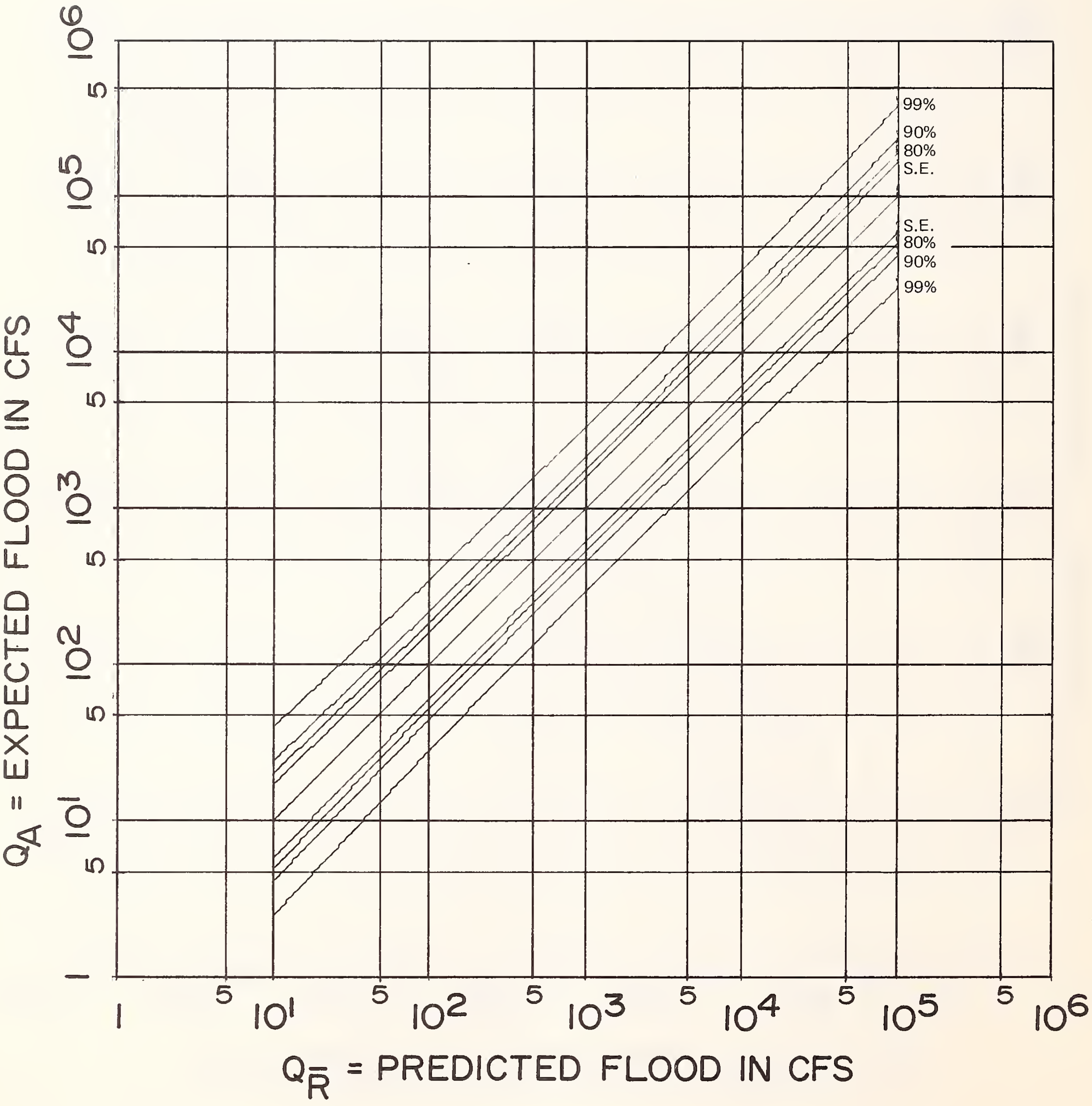
CONFIDENCE INTERVALS FOR REGION III



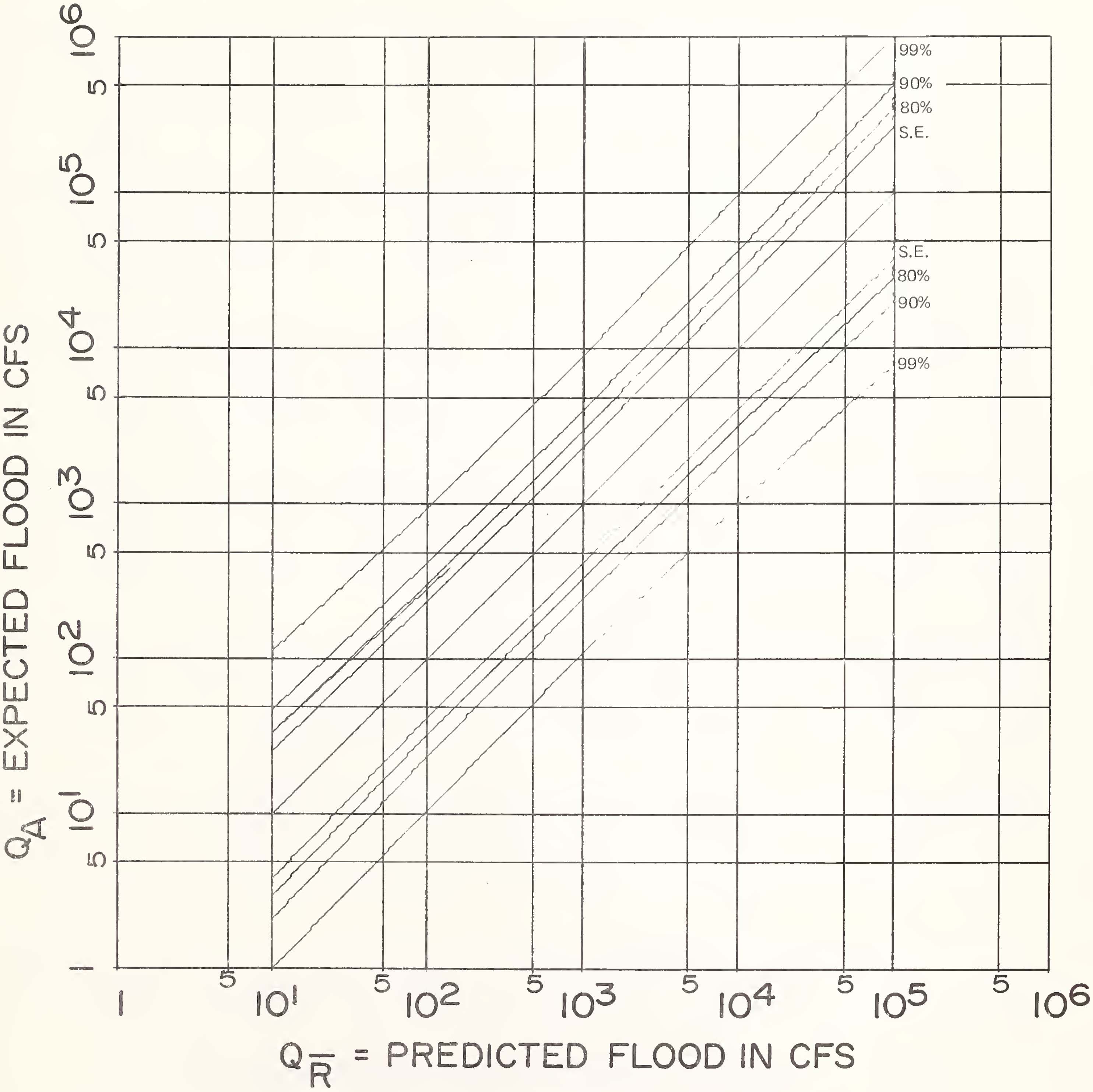
CONFIDENCE INTERVALS FOR REGION IV



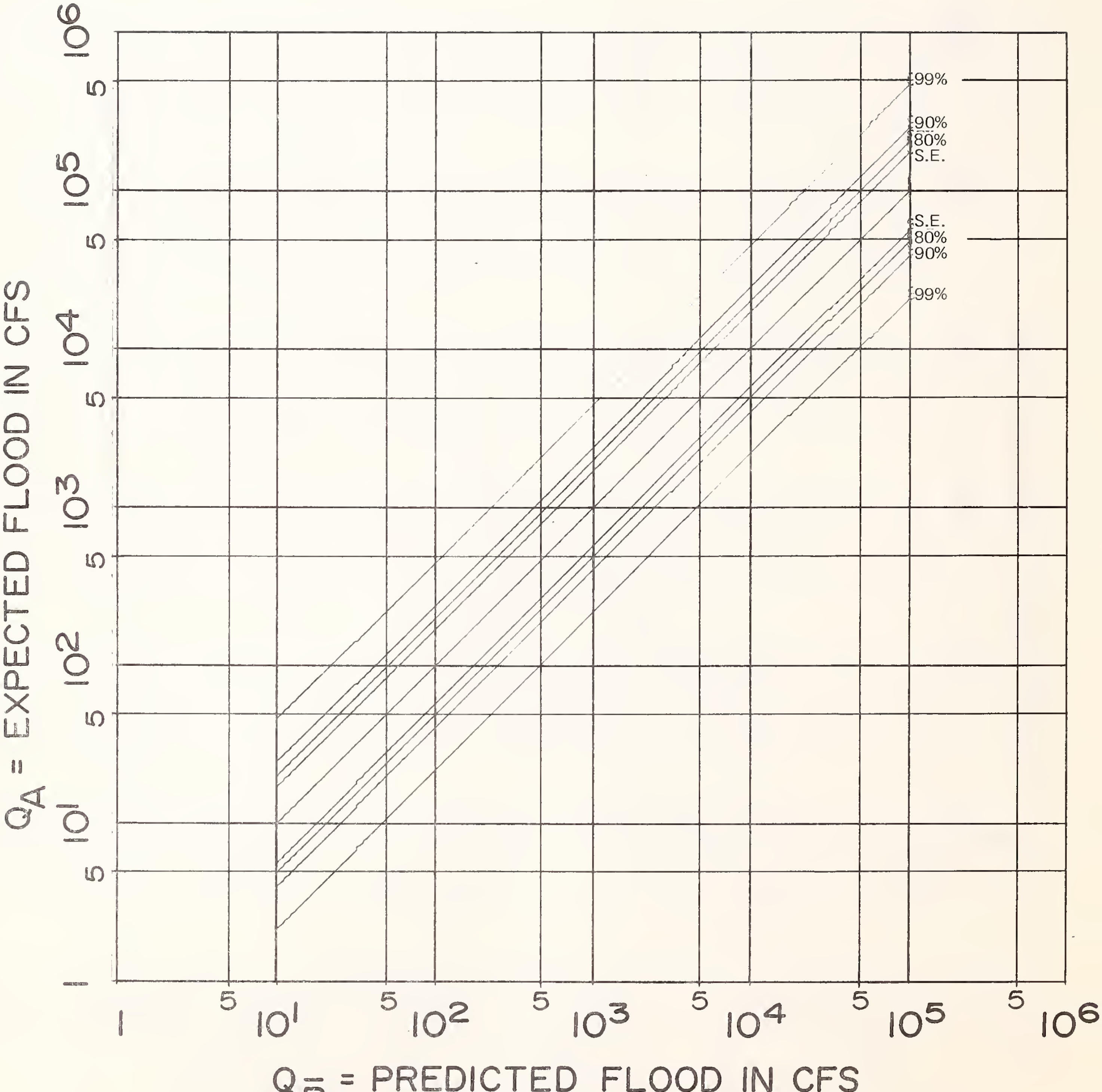
CONFIDENCE INTERVALS FOR REGION V



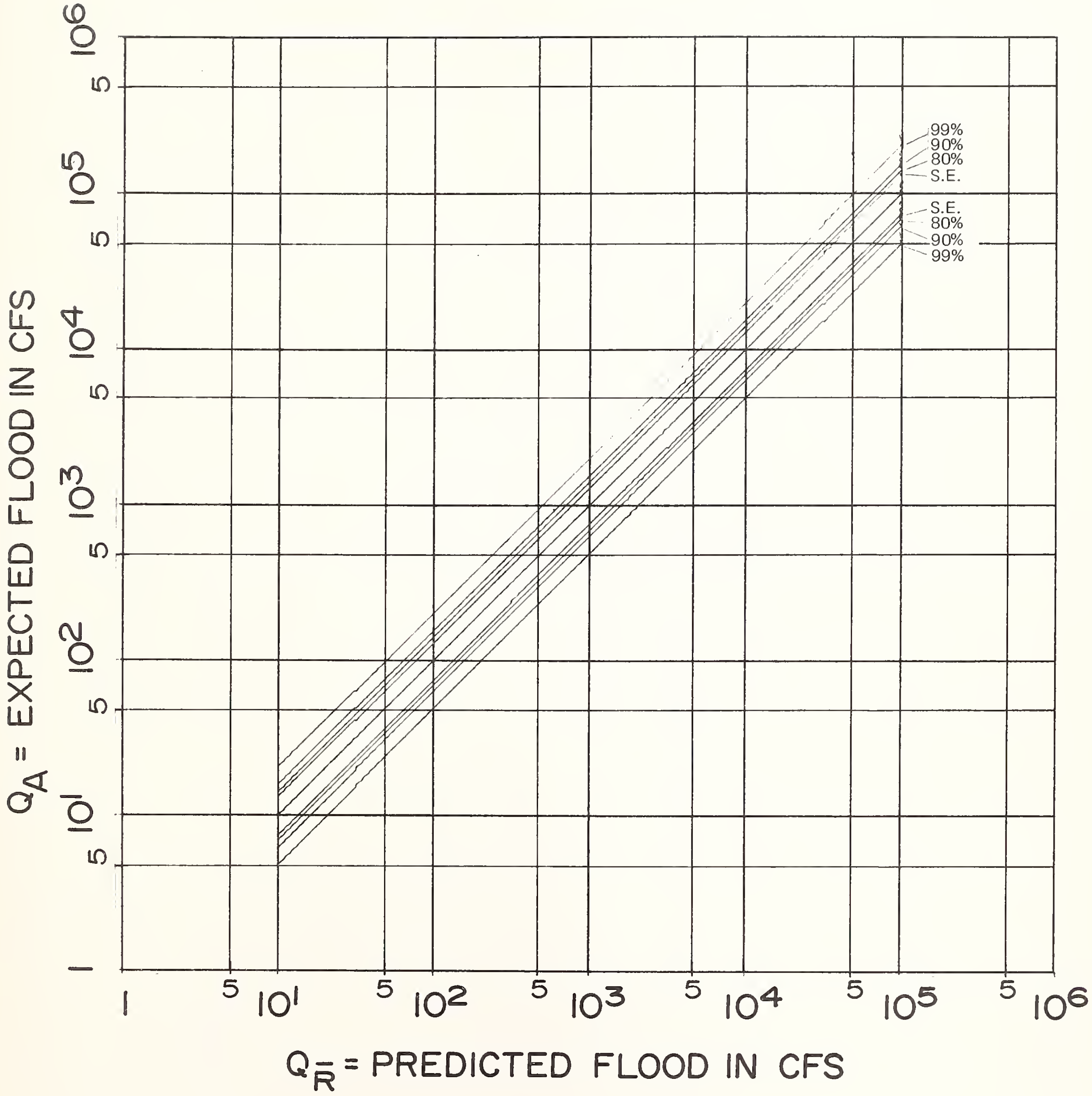
CONFIDENCE INTERVALS FOR REGION VI



CONFIDENCE INTERVALS FOR REGION VII



CONFIDENCE INTERVALS FOR REGION VIII



CONFIDENCE INTERVALS FOR REGION IX

APPENDIX D

HYDRAULIC DESIGN TABLES AND CHARTS

TABLE OF CONTENTS

PAGE

Table 1 Coefficient of Runoff C for use Rational Formula 1

Table 2 Manning n for Channels and Natural Streams 2

Table 3 Geometric Elements Circular Section Partially Full 4

Table 4 Uniform Flow in Rectangular Channels by Manning's Formula 7

Fig. 1 Nomograph for Solution of Manning Equation 8

Fig. 2 Diagram for Solution of Manning Equation for Circular Pipe Flowing Full (n = .013) 9

Fig. 3 Hydraulic Elements of a Circular Pipe 10

Fig. 4 Kirpich Nomograph for Estimating Time of Concentration, T_c 11

Fig. 5 1969 ESSA 2-year 24-hour Storm Rainfall Map of Montana . . 12

Rainfall Intensity-Duration-Frequency Curves

Area I Great Falls-Kalispell Area 13

Area II Billings Area 14

Area III Miles City Area 15

Area IV Helena-Bozeman-Butte Area 16

Flow Circular Pipes, D = 12-96 inch Partly Full Uniform Flow, n = .012, .015, .024 Critical Depth 17-33

Table 1

Coefficient of Runoff - C
For Use Rational Formula

$$Q = C\, i\, A$$

TYPE SURFACE		VALUES C	
		Min	Max
Roofs		.75	.95
Pavements			
Portland Cement, Asphaltic Concrete		.80	.95
Bituminous, open graded or cracked		.70	.95
Gravel Roadway			
From clean & loose to clayey & hard		.25	.70
Earth, bare to dense grass or vegetation			
Flat (2%), Steep (7%)			
Sandy, from uniform size to fines	Bare	.15	.50
AHO flat, to graded, some	Light vegetation	.10	.40
silt AHO clay and steep	Dense vegetation	.05	.30
Loam, from sandy or gravely AHO	Bare	.20	.60
Flat, to clayey and steep	Light vegetation	.10	.45
	Dense vegetation	.05	.35
Gravel, from clean AHO loose and	Bare	.25	.65
flat, to high silt or clay AHO steep	Light vegetation	.15	.50
Clay, from sandy or silty AHO	Bare	.30	.75
flat, to dense clay AHO	Light vegetation	.20	.60
Steep	Dense vegetation	.15	.50
Railroad Yards		.10	.30
Composite Urban Areas			
Business Blocks			
Densely built		.70	.95
Moderately built, some open space		.50	.70
Residential blocks			
Suburban		.25	.40
Single family, dense		.30	.50
Multiple family, detached		.40	.60
Multiple family, continuous		.60	.70
Apartments		.50	.70
Industrial Blocks			
Light, some open space		.40	.80
Densely built		.60	.90
Parks, Golf courses, Cemeteries		.10	.30
Playgrounds		.20	.45
Unimproved Land		.10	.30
Highway Slopes and Ditches			
See earth, bare to dense grass or vegetation			

Table 2

Mannings n For Channels
And Natural Streams

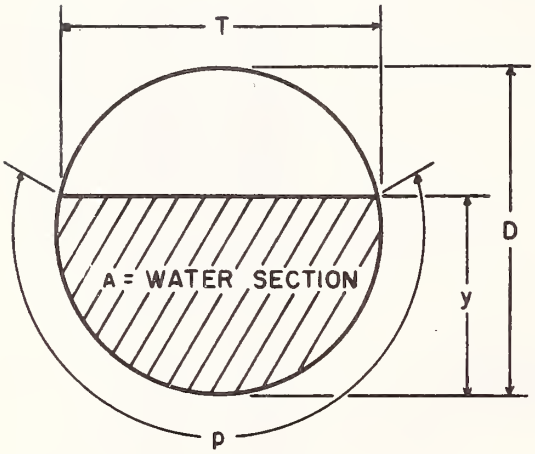
	Range	Ordinary Design Value
Open Channels-lined		
Asphalt		
Smooth		.013
Rough		.016
Concrete		
Smooth forms or troweled	.011-.015	.013
Float finish	.013-.016	.014
Unfinished	.014-.020	.017
Gunite, good		.019
Gunite, wavy		.022
Cemented rubble masonry	.017-.030	.025
Dressed ashlar masonry	.013-.017	.015
Buck in Mortar	.012-.018	.015
Open Channels		
Excavated		
Earth, uniform and straight		
clean, neat-new to weathered	.016-.022	
short grass, few weeds	.022-.027	
gravelly soil, clean	.022-.030	
Earth, winding		
Clean	.023-.030	
Grass, some weeds	.025-.033	
Dense weeds or aquatic plants	.030-.040	
Stony bottom and weedy banks	.025-.040	
Dragline Excavated		
No vegetation	.025-.030	
Light brush on banks	.035-.060	
Channels not maintained, weeds and brush uncut		
Dense weeds to flow depth	.050-.120	
Clean bottom, brush on banks	.040-.080	
Dense brush, high stage	.080-.140	
Rock cuts		
Fairly smooth and uniform	.025-.040	
Rather irregular	.035-.050	
Natural Streams (top width at flood stage 100ft)		
Streams on prairie, plain, or valley floor		
Fairly regular section		
Clean, straight, no rifts or deep pools	.025-.033	.030
Clean, winding, some pools and shoals	.033-.045	.040
Clean, winding, some weeds and stones	.035-.050	.045
Clean, winding, more weeds and stones	.045-.060	.050
Sluggish reaches, weedy deep pools	.050-.080	.070
Floodways with heavy stand timber underbrush	.075-.150	.100
Mountain Streams with trees and brush along banks submerged at high stages		
Bottom gravel, cobbles, and few boulders	.030-.050	.040
Bottom with large boulders	.040-.070	.050

Table 2 (Contd.)

	Range	Ordinary Design Values
Flood Plains (adjacent to natural streams)		
Pasture, short to high grass	.030-.050	
Cultivated areas		
no crop	.030-.040	
Mature row crops	.025-.045	
Mature field crops	.030-.050	
Heavy Weeds, scattered brush	.035-.070	
Light brush and trees		
winter to summer	.05 - .08	
Medium brush and trees		
winter to summer	.07 - .16	
Dense willows, summer, not bent over	.15 - 2.0	
Cleared land with tree stumps, 100-150		
no sprouts	.04 - .05	
heavy growth sprouts	.16 - .08	
Heavy stand timber, some sown		
little brush or undergrowth		
water below branches	.10 - .12	
water reaching branches	.12 - .16	
Major Streams (surface at flood stage 100 ft)		
n value usually less than for minor streams of like description because banks offer relatively less resistance		
Large stream, regular section, no branch or boulders	.025-.060	
Large stream, irregular with boulders and some brush	.035-.100	

Table 3

Geometric Elements Circular Section Partially Full



$r = \frac{A}{P}$ = HYDRAULIC RADIUS

Q = DISCHARGE, cfs

$\frac{y}{D}$	$\frac{A}{D^2}$	$\frac{P}{D}$	$\frac{r}{D}$	$\frac{T}{D}$	$\frac{Ar^{2/3}}{D^{8/3}}$	$\frac{Q}{g^{1/2}D^{5/2}}$
0.01	0.0013	0.2003	0.0066	0.1990	0.0000	0.0001
0.02	0.0037	0.2838	0.0132	0.2800	0.0002	0.0004
0.03	0.0069	0.3482	0.0197	0.3412	0.0005	0.0010
0.04	0.0105	0.4027	0.0262	0.3919	0.0009	0.0017
0.05	0.0147	0.4510	0.0326	0.4359	0.0015	0.0027
0.06	0.0192	0.4949	0.0389	0.4750	0.0022	0.0039
0.07	0.0242	0.5355	0.0451	0.5103	0.0031	0.0053
0.08	0.0294	0.5735	0.0513	0.5426	0.0040	0.0069
0.09	0.0350	0.6094	0.0574	0.5724	0.0052	0.0087
0.10	0.0409	0.6435	0.0635	0.6000	0.0065	0.0107
0.11	0.0470	0.6761	0.0695	0.6258	0.0079	0.0129
0.12	0.0534	0.7075	0.0754	0.6499	0.0095	0.0153
0.13	0.0600	0.7377	0.0813	0.6726	0.0113	0.0179
0.14	0.0668	0.7670	0.0871	0.6940	0.0131	0.0217
0.15	0.0739	0.7954	0.0929	0.7141	0.0152	0.0238
0.16	0.0811	0.8230	0.0986	0.7332	0.0173	0.0270
0.17	0.0885	0.8500	0.1042	0.7513	0.0196	0.0304
0.18	0.0961	0.8763	0.1097	0.7684	0.0220	0.0339
0.19	0.1039	0.9020	0.1152	0.7846	0.0247	0.0378
0.20	0.1118	0.9273	0.1206	0.8000	0.0273	0.0418
0.21	0.1199	0.9521	0.1259	0.8146	0.0301	0.0460
0.22	0.1281	0.9764	0.1312	0.8285	0.0333	0.0503
0.23	0.1365	0.0003	0.1364	0.8417	0.0359	0.0549
0.24	0.1449	0.0239	0.1416	0.8542	0.0394	0.0597
0.25	0.1535	0.0472	0.1466	0.8660	0.0427	0.0646

Table 3 (contd.)

$\frac{y}{D}$	$\frac{A}{D^2}$	$\frac{P}{D}$	$\frac{r}{D}$	$\frac{T}{D}$	$\frac{Ar^{2/3}}{D^{8/3}}$	$\frac{Q}{g^{1/2}D^{5/2}}$
0.26	0.1623	1.0701	0.1516	0.8773	0.0464	0.0697
0.27	0.1711	1.0928	0.1566	0.8879	0.0497	0.0751
0.28	0.1800	1.1152	0.1614	0.8980	0.0536	0.0805
0.29	0.1890	1.1373	0.1662	0.9075	0.0571	0.0862
0.30	0.1982	1.1593	0.1709	0.9165	0.0610	0.0921
0.31	0.2074	1.1810	0.1755	0.9250	0.0650	0.0981
0.32	0.2167	1.2025	0.1801	0.9330	0.0690	0.1044
0.33	0.2260	1.2239	0.1848	0.9404	0.0736	0.1107
0.34	0.2355	1.2451	0.1891	0.9474	0.0776	0.1172
0.35	0.2450	1.2661	0.1935	0.9539	0.0820	0.1241
0.36	0.2546	1.2870	0.1978	0.9600	0.0864	0.1310
0.37	0.2642	1.3078	0.2020	0.9656	0.0909	0.1381
0.38	0.2739	1.3284	0.2061	0.9708	0.0955	0.1453
0.39	0.2836	1.3490	0.2102	0.9755	0.1020	0.1528
0.40	0.2934	1.3694	0.2142	0.9798	0.1050	0.1603
0.41	0.3032	1.3898	0.2181	0.9837	0.1100	0.1682
0.42	0.3132	1.4101	0.2220	0.9871	0.1147	0.1761
0.43	0.3229	1.4303	0.2257	0.9902	0.1196	0.1844
0.44	0.3328	1.4505	0.2294	0.9928	0.1245	0.1927
0.45	0.3428	1.4706	0.2331	0.9950	0.1298	0.2011
0.46	0.3527	1.4907	0.2366	0.9968	0.1348	0.2098
0.47	0.3627	1.5108	0.2400	0.9982	0.1401	0.2186
0.48	0.3727	1.5308	0.2434	0.9992	0.1452	0.2275
0.49	0.3827	1.5508	0.2467	0.9998	0.1505	0.2366
0.50	0.3927	1.5708	0.2500	1.0000	0.1558	0.2459
0.51	0.4027	1.5908	0.2531	0.9998	0.1610	0.2553
0.52	0.4127	1.6108	0.2561	0.9992	0.1664	0.2650
0.53	0.4227	1.6308	0.2591	0.9982	0.1715	0.2748
0.54	0.4327	1.6509	0.2620	0.9968	0.1772	0.2848
0.55	0.4426	1.6710	0.2649	0.9950	0.1825	0.2949
0.56	0.4526	1.6911	0.2676	0.9928	0.1878	0.3051
0.57	0.4625	1.7113	0.2703	0.9902	0.1933	0.3158
0.58	0.4723	1.7315	0.2728	0.9871	0.1987	0.3263
0.59	0.4822	1.7518	0.2753	0.9837	0.2041	0.3373
0.60	0.4920	1.7722	0.2776	0.9798	0.2092	0.3484
0.61	0.5018	1.7926	0.2797	0.9755	0.2146	0.3560
0.62	0.5115	1.8132	0.2818	0.9708	0.2199	0.3710
0.63	0.5212	1.8338	0.2839	0.9656	0.2252	0.3830
0.64	0.5308	1.8546	0.2860	0.9600	0.2302	0.3945
0.65	0.5404	1.8755	0.2881	0.9539	0.2358	0.4066
0.66	0.5499	1.8965	0.2899	0.9474	0.2407	0.4188
0.67	0.5594	1.9177	0.2917	0.9404	0.2460	0.4309
0.68	0.5687	1.9391	0.2935	0.9330	0.2510	0.4437
0.69	0.5780	1.9606	0.2950	0.9250	0.2560	0.4566
0.70	0.5872	1.9823	0.2962	0.9165	0.2608	0.4694

Table 3 (contd.)

$\frac{y}{D}$	$\frac{A}{D^2}$	$\frac{P}{D}$	$\frac{r}{D}$	$\frac{T}{D}$	$\frac{Ar^{2/3}}{D^{8/3}}$	$\frac{Q}{g^{1/2}D^{5/2}}$
0.71	0.5964	2.0042	0.2973	0.9075	0.2653	0.4831
0.72	0.6054	2.0264	0.2984	0.8980	0.2702	0.4964
0.73	0.6143	2.0488	0.2995	0.8879	0.2751	0.5100
0.74	0.6231	2.0714	0.3006	0.8773	0.2794	0.5248
0.75	0.6318	2.0944	0.3017	0.8660	0.2840	0.5392
0.76	0.6404	2.1176	0.3025	0.8542	0.2888	0.5540
0.77	0.6489	2.1412	0.3032	0.8417	0.2930	0.5695
0.78	0.6573	2.1652	0.3037	0.8285	0.2969	0.5850
0.79	0.6655	2.1895	0.3040	0.8146	0.3008	0.6011
0.80	0.6736	2.2143	0.3042	0.8000	0.3045	0.6177
0.81	0.6815	2.2395	0.3044	0.7846	0.3082	0.6347
0.82	0.6893	2.2653	0.3043	0.7684	0.3118	0.6524
0.83	0.6969	2.2916	0.3041	0.7513	0.3151	0.6707
0.84	0.7043	2.3186	0.3038	0.7332	0.3182	0.6897
0.85	0.7115	2.3462	0.3033	0.7141	0.3212	0.7098
0.86	0.7186	2.3746	0.3026	0.6940	0.3240	0.7307
0.87	0.7254	2.4038	0.3017	0.6726	0.3264	0.7528
0.88	0.7320	2.4341	0.3008	0.6499	0.3286	0.7754
0.89	0.7380	2.4655	0.2996	0.6258	0.3307	0.8016
0.90	0.7445	2.4981	0.2980	0.6000	0.3324	0.8285
0.91	0.7504	2.5322	0.2963	0.5724	0.3336	0.8586
0.92	0.7560	2.5681	0.2944	0.5426	0.3345	0.8917
0.93	0.7612	2.6061	0.2922	0.5103	0.3350	0.9292
0.94	0.7662	2.6467	0.2896	0.4750	0.3353	0.9725
0.95	0.7707	2.6906	0.2864	0.4359	0.3349	1.0242
0.96	0.7749	2.7389	0.2830	0.3919	0.3340	1.0888
0.97	0.7785	2.7934	0.2787	0.3412	0.3322	1.1752
0.98	0.7816	2.8578	0.2735	0.2800	0.3291	1.3050
0.99	0.7841	2.9412	0.2665	0.1990	0.3248	1.5554
1.00	0.7854	3.1416	0.2500	0.0000	0.3117	∝

Table 4

Uniform Flow in Rectangular Channels

By Manning's Formula

$$F = \frac{Qn}{S_o^{1/2}\ B^{8/3}}$$

y/B	F	y/B	F	y/B	F	y/B	F	y/B	F
		.21	.0873	.41	.225	.72	.474	1.30	.980
.02	.00213	.22	.0935	.42	.233	.74	.491	1.35	1.02
.03	.00414	.23	.0997	.43	.241	.76	.508	1.40	1.07
.04	.00661	.24	.106	.44	.249	.78	.525	1.45	1.11
.05	.00947	.25	.113	.45	.256	.80	.542	1.50	1.16
.06	.0127	.26	.119	.46	.263	.82	.559	1.55	1.20
.07	.0162	.27	.126	.47	.271	.84	.576	1.60	1.25
.08	.0200	.28	.133	.48	.279	.86	.593	1.65	1.30
.09	.0240	.29	.139	.49	.287	.88	.610	1.70	1.34
.10	.0283	.30	.146	.50	.295	.90	.627	1.75	1.39
.11	.0329	.31	.153	.52	.310	.92	.645	1.80	1.43
.12	.0376	.32	.160	.54	.327	.94	.662	1.85	1.48
.13	.0425	.33	.167	.56	.343	.96	.680	1.90	1.52
.14	.0476	.34	.174	.58	.359	.98	.697	1.95	1.57
.15	.0528	.35	.181	.60	.375	1.00	.714	2.00	1.61
.16	.0582	.36	.190	.62	.391	1.05	.759	2.10	1.71
.17	.0638	.37	.196	.64	.408	1.10	.802	2.20	1.79
.18	.0695	.38	.203	.66	.424	1.15	.846	2.30	1.89
.19	.0753	.39	.210	.68	.441	1.20	.891	2.40	1.98
.20	.0813	.40	.218	.70	.457	1.25	.936	2.50	2.07

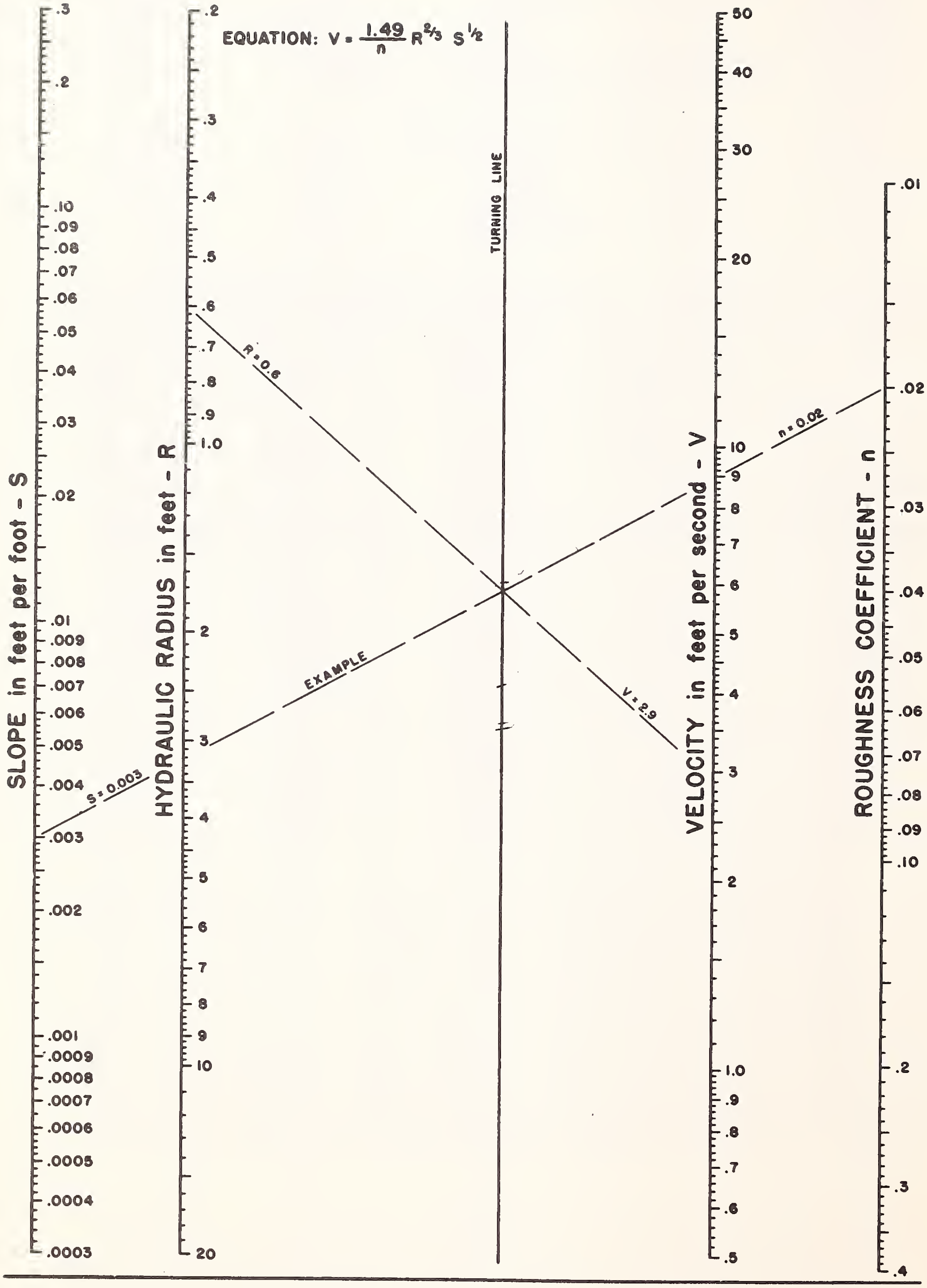


Fig. 1 Nomograph for Solution to Manning Equation

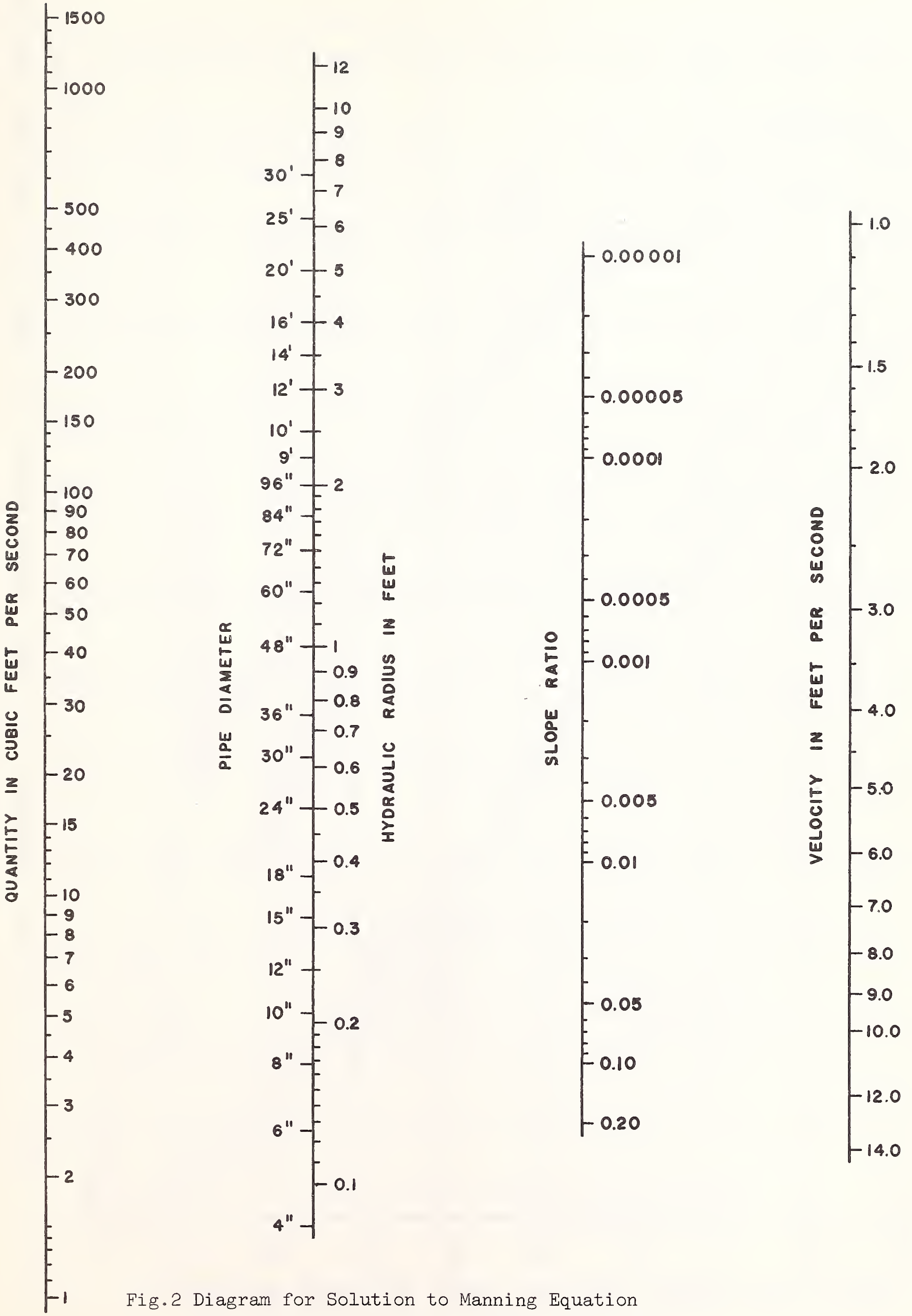


Fig.2 Diagram for Solution to Manning Equation For Circular Pipe Flowing Full (n=0.013)

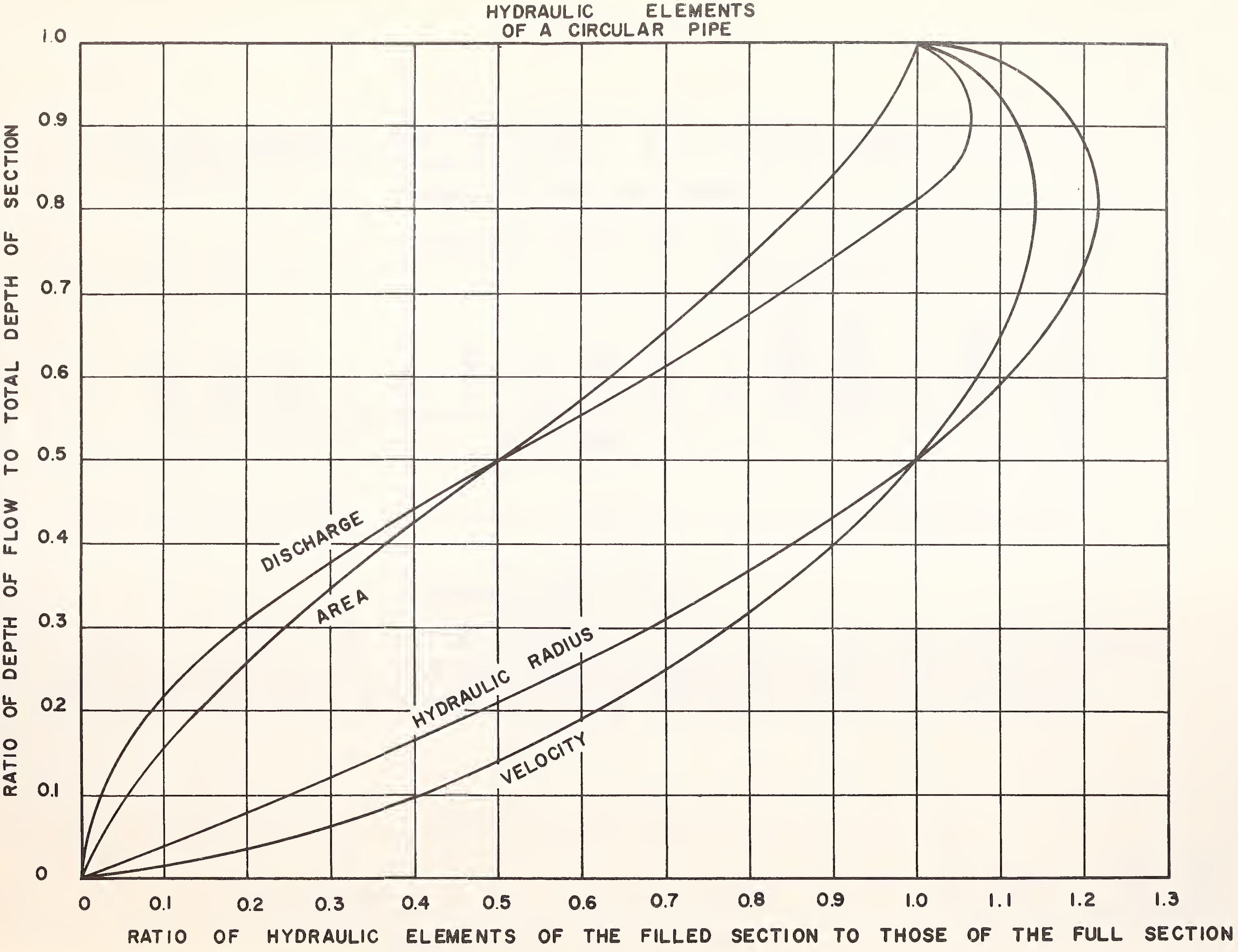


Fig. 3 Hydraulic Elements of a Circular Pipe

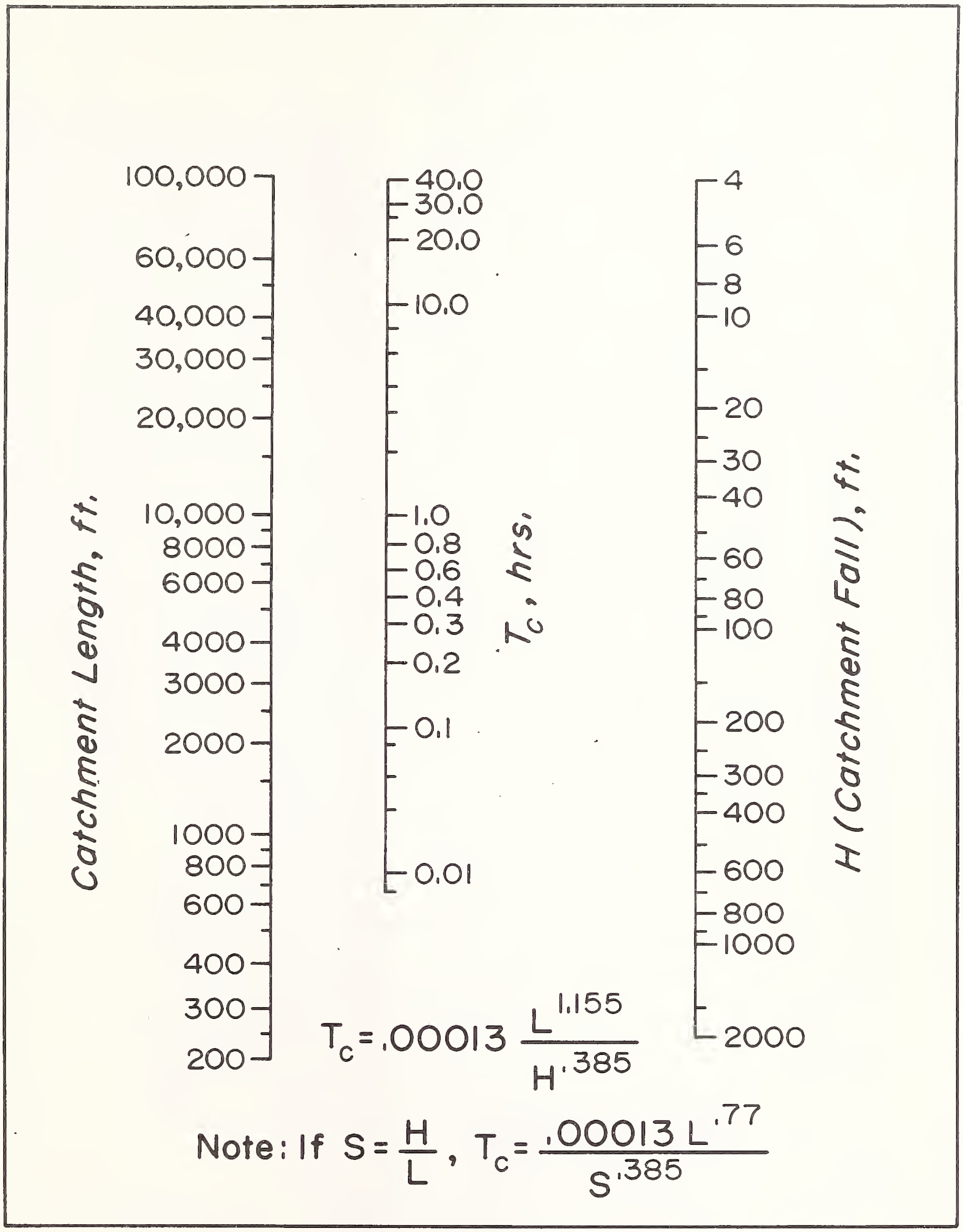
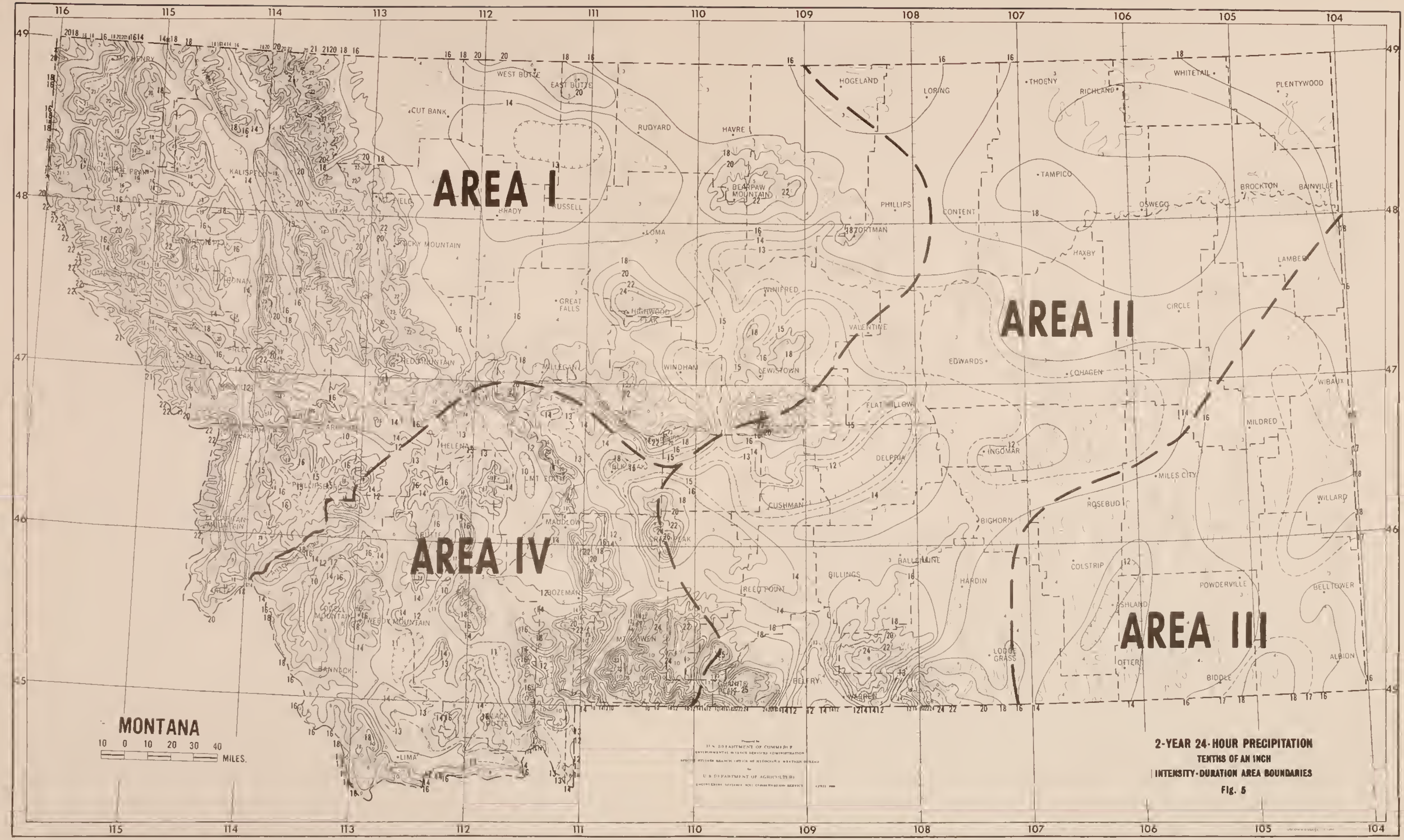


Fig. 4 Kirpich Nomograph for Estimating Time of Concentration, T_c

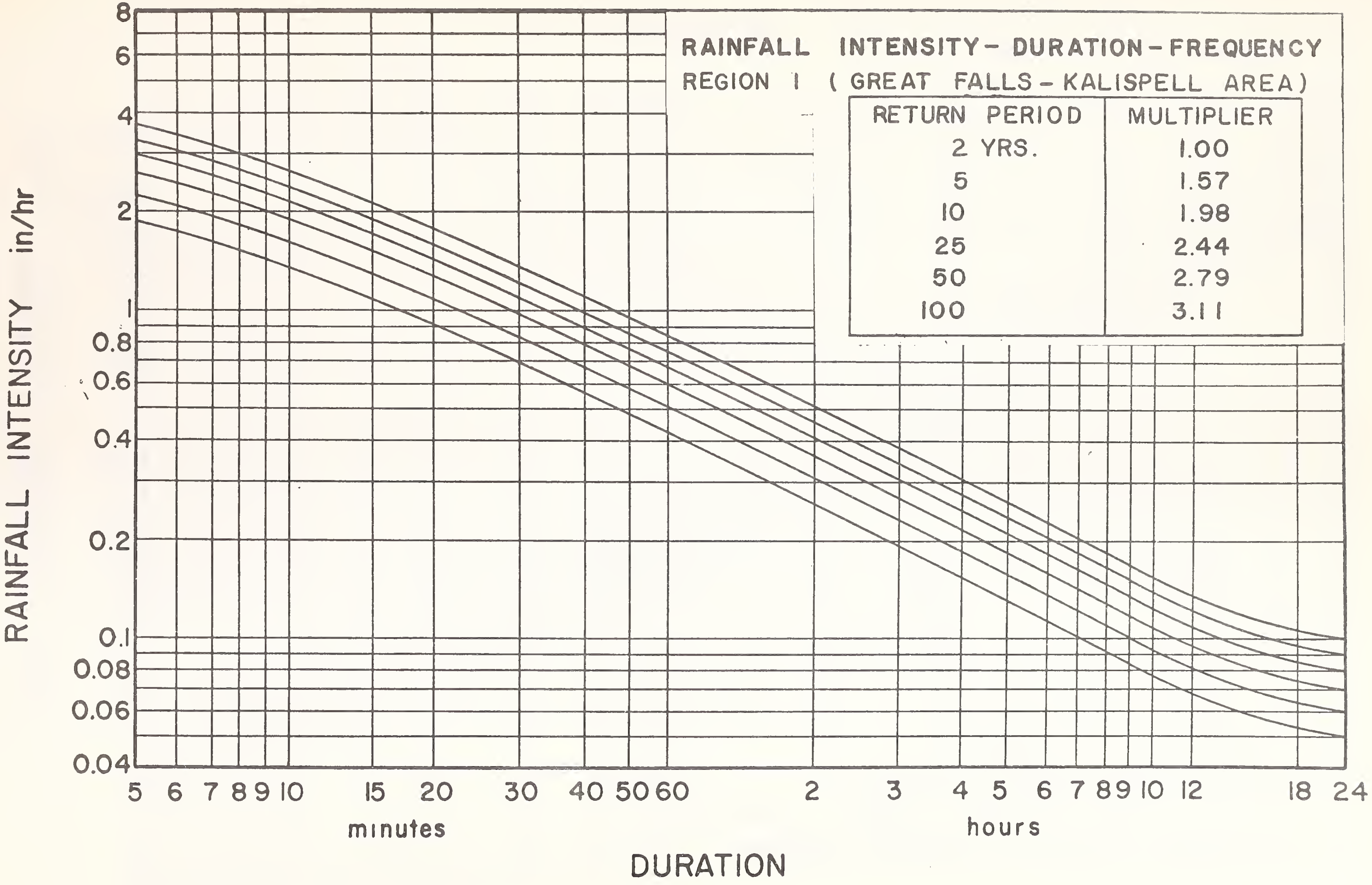


2-YEAR 24-HOUR PRECIPITATION

TENTHS OF AN INCH

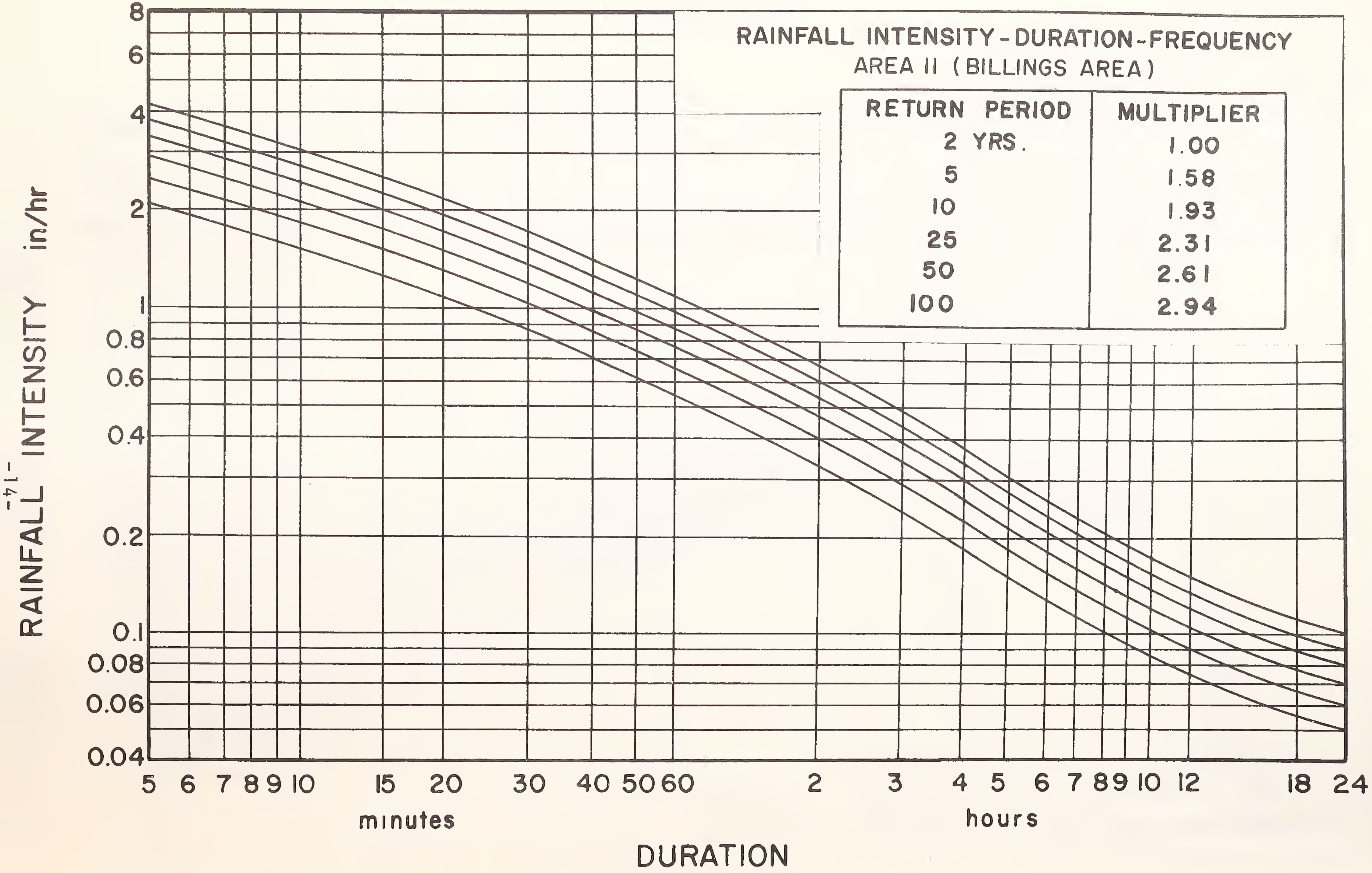
INTENSITY-DURATION AREA BOUNDARIES

Fig. 5



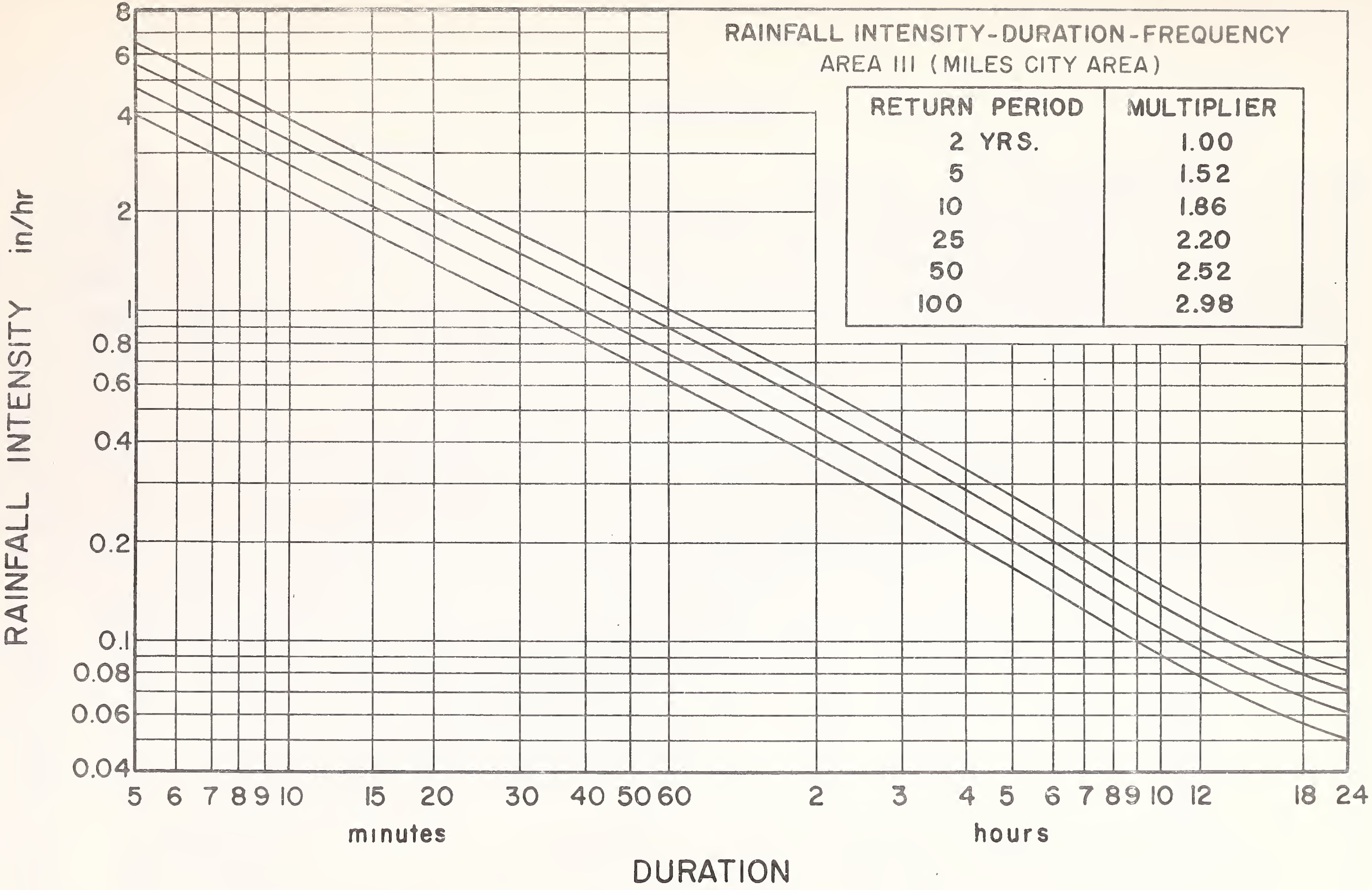
RAINFALL INTENSITY - DURATION - FREQUENCY
REGION I (GREAT FALLS - KALISPELL AREA)

RETURN PERIOD	MULTIPLIER
2 YRS.	1.00
5	1.57
10	1.98
25	2.44
50	2.79
100	3.11



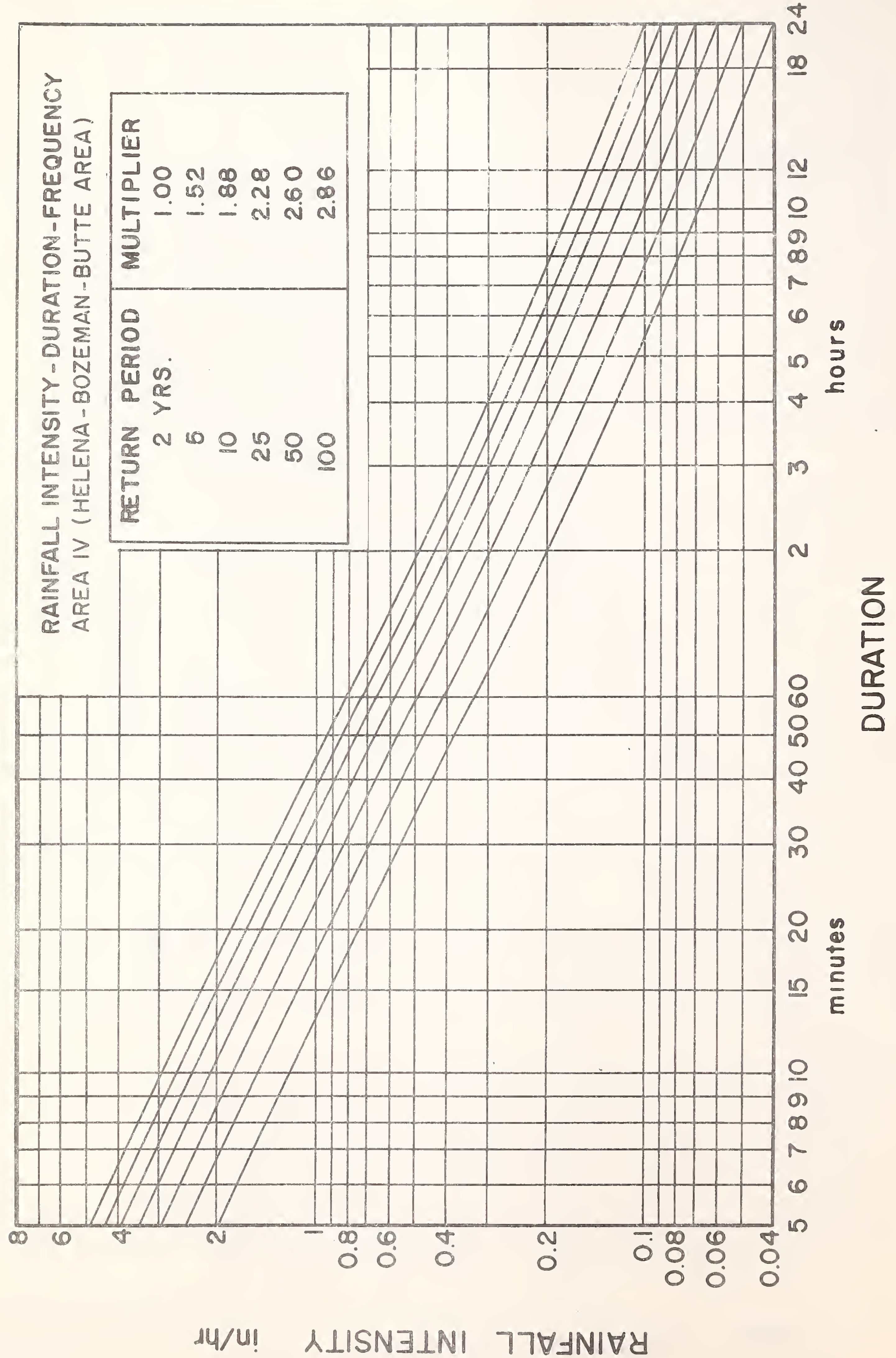
RAINFALL INTENSITY - DURATION - FREQUENCY
AREA II (BILLINGS AREA)

RETURN PERIOD	MULTIPLIER
2 YRS.	1.00
5	1.58
10	1.93
25	2.31
50	2.61
100	2.94



RAINFALL INTENSITY-DURATION-FREQUENCY
AREA III (MILES CITY AREA)

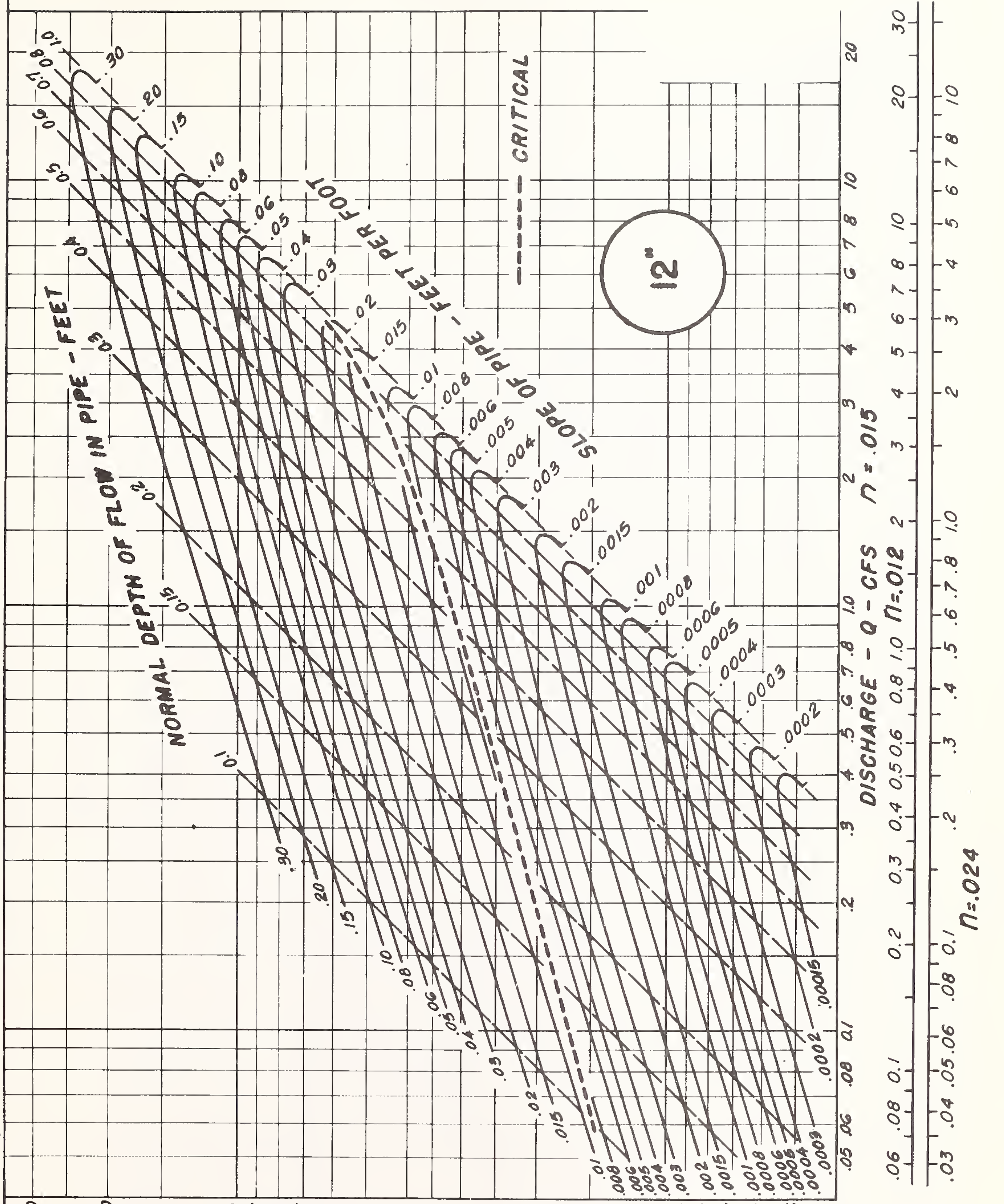
RETURN PERIOD	MULTIPLIER
2 YRS.	1.00
5	1.52
10	1.86
25	2.20
50	2.52
100	2.98



RAINFALL INTENSITY-DURATION-FREQUENCY
AREA IV (HELENA-BOZEMAN-BUTTE AREA)

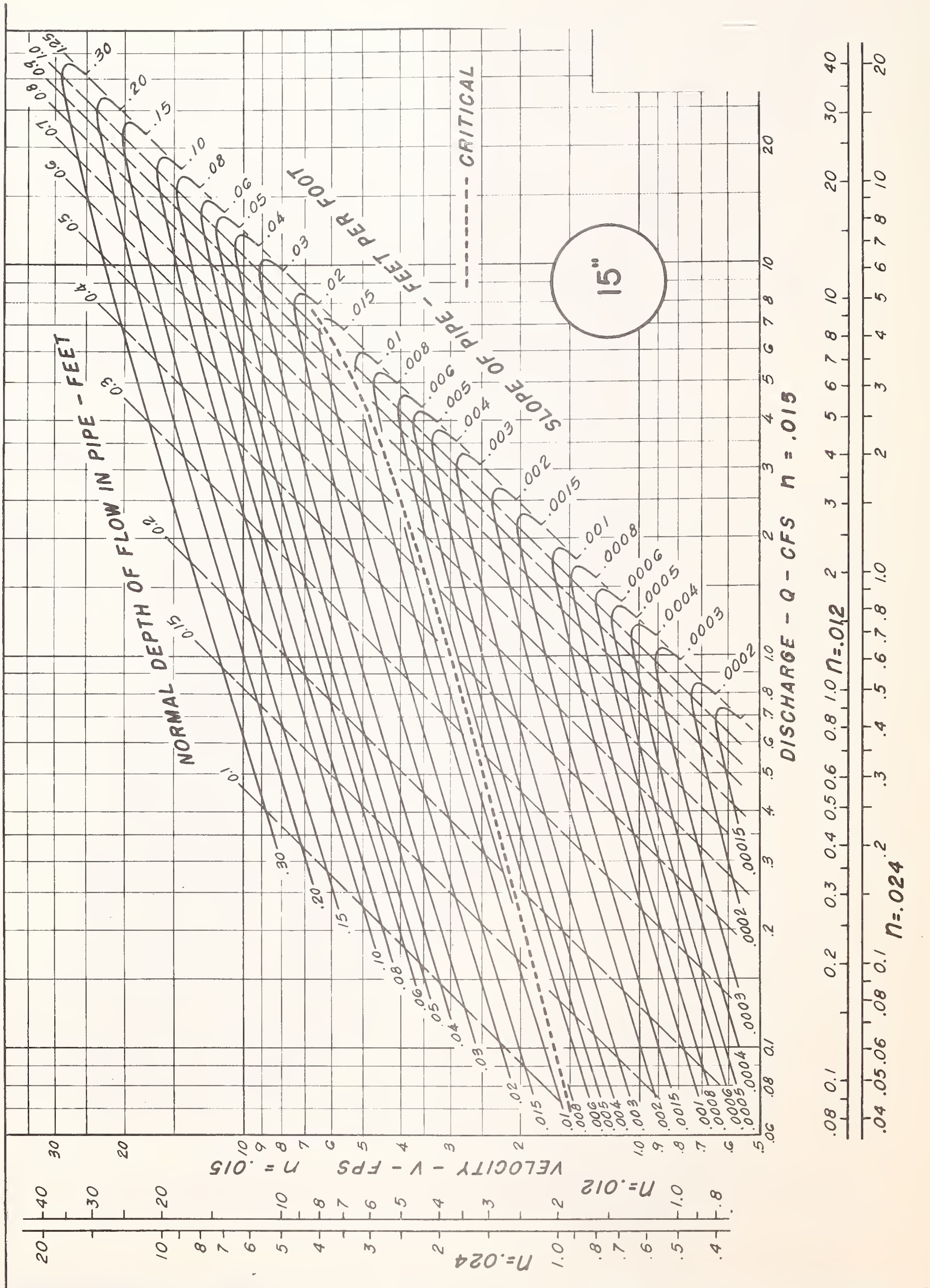
RETURN PERIOD	MULTIPLIER
2 YRS.	1.00
5	1.52
10	1.88
25	2.28
50	2.60
100	2.86

CHART I



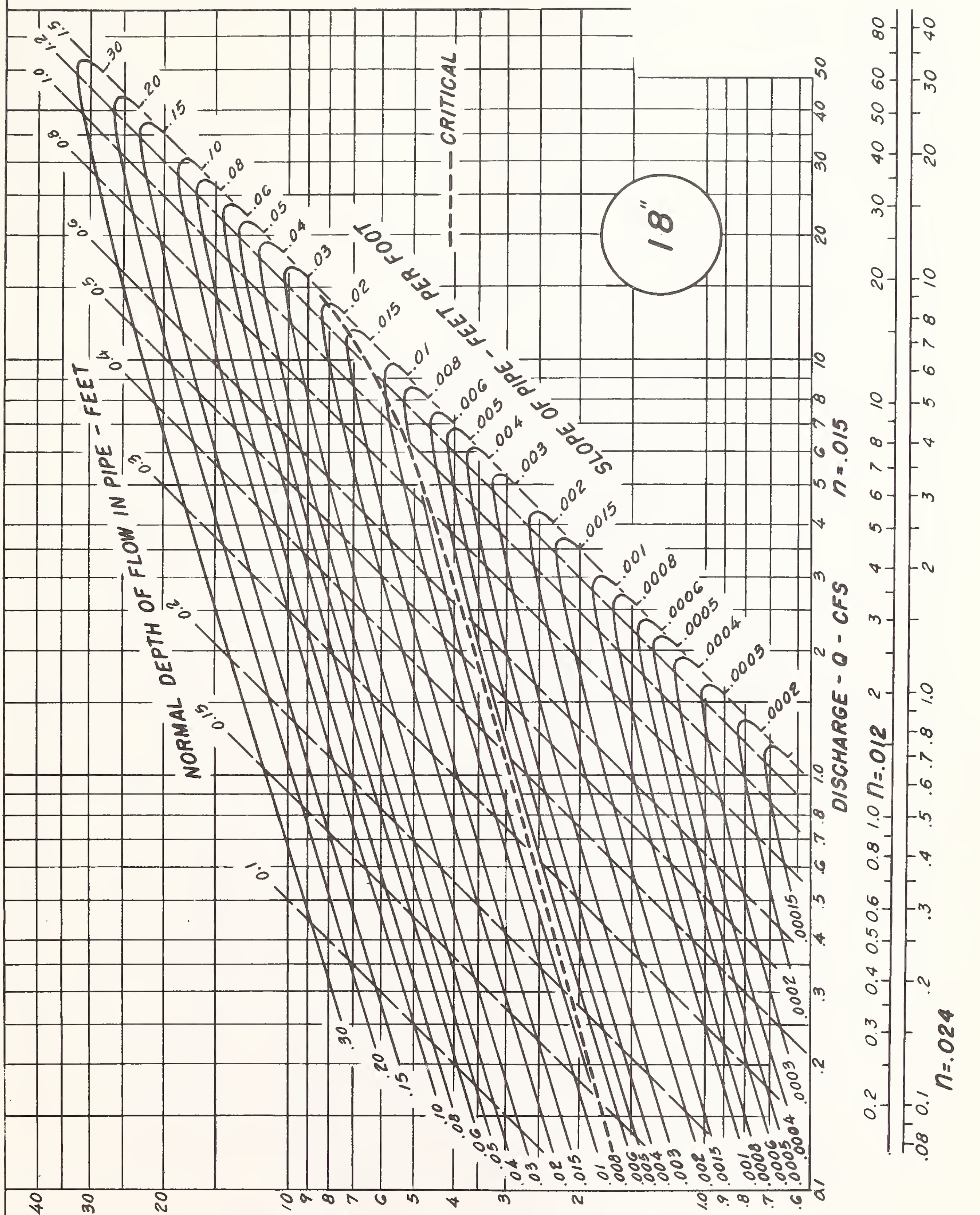
PIPE FLOW CHART
12-INCH DIAMETER

CHART 2

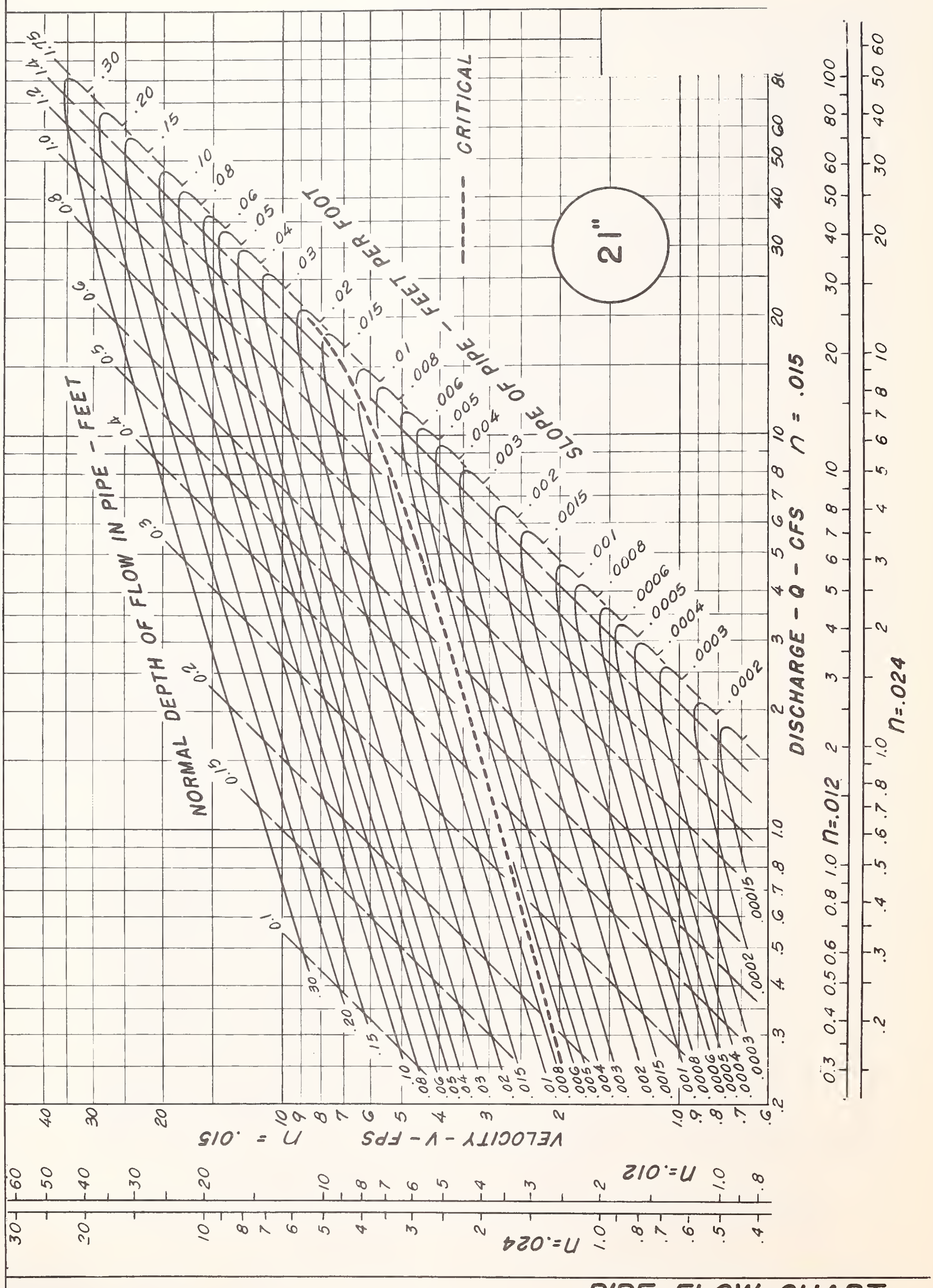


PIPE FLOW CHART
15-INCH DIAMETER

CHART 3

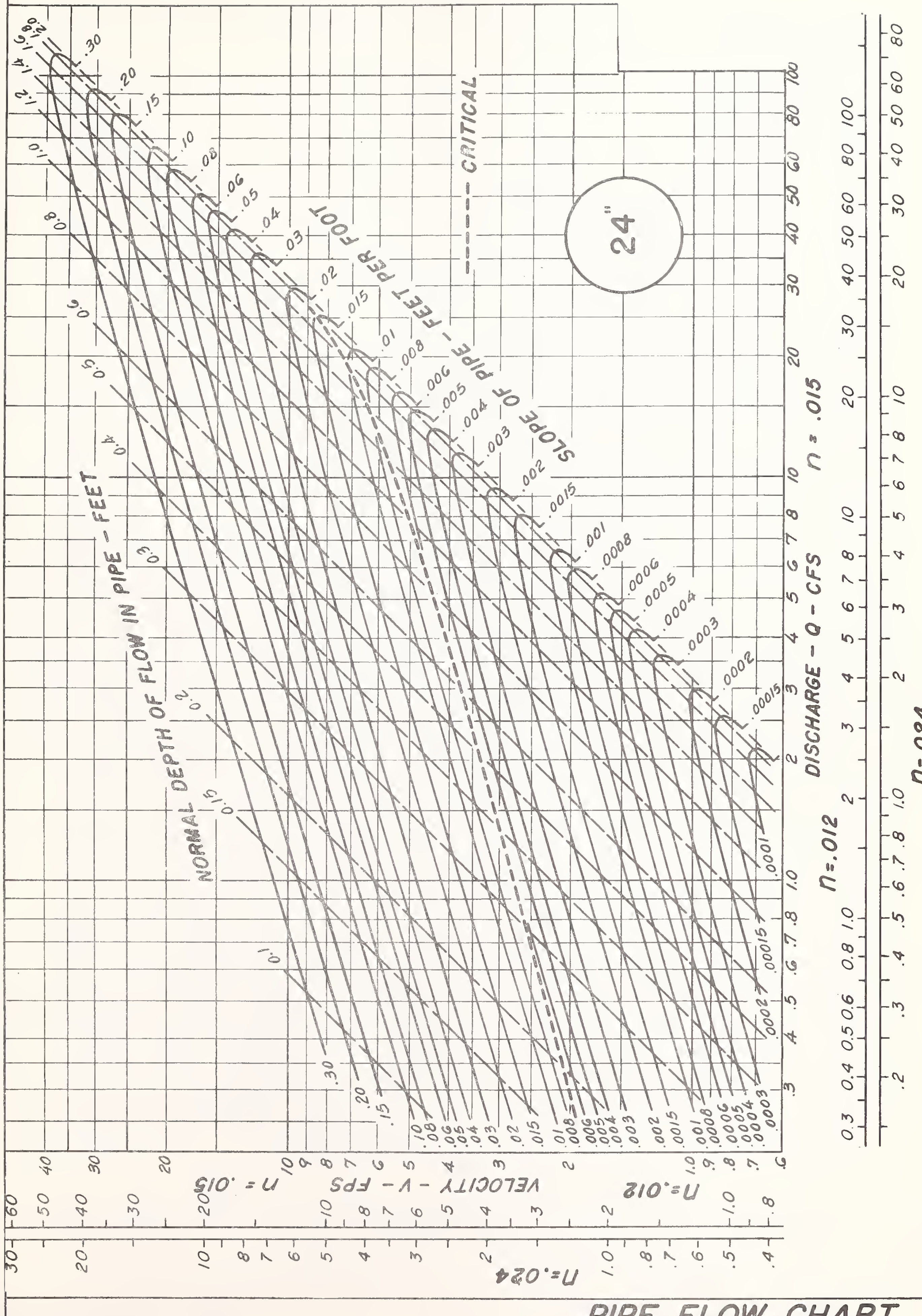


PIPE FLOW CHART
18-INCH DIAMETER



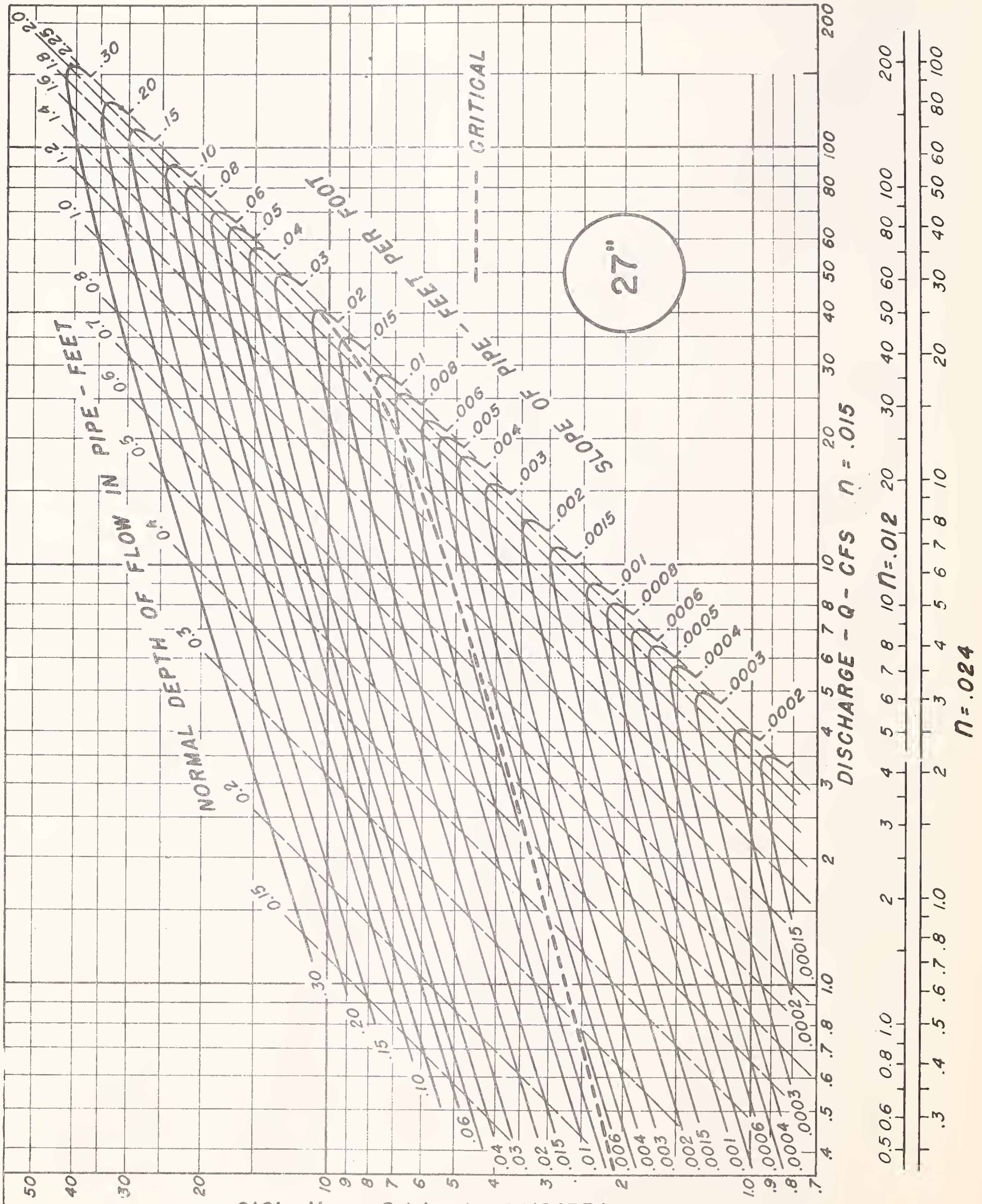
PIPE FLOW CHART
21-INCH DIAMETER

CHART 5



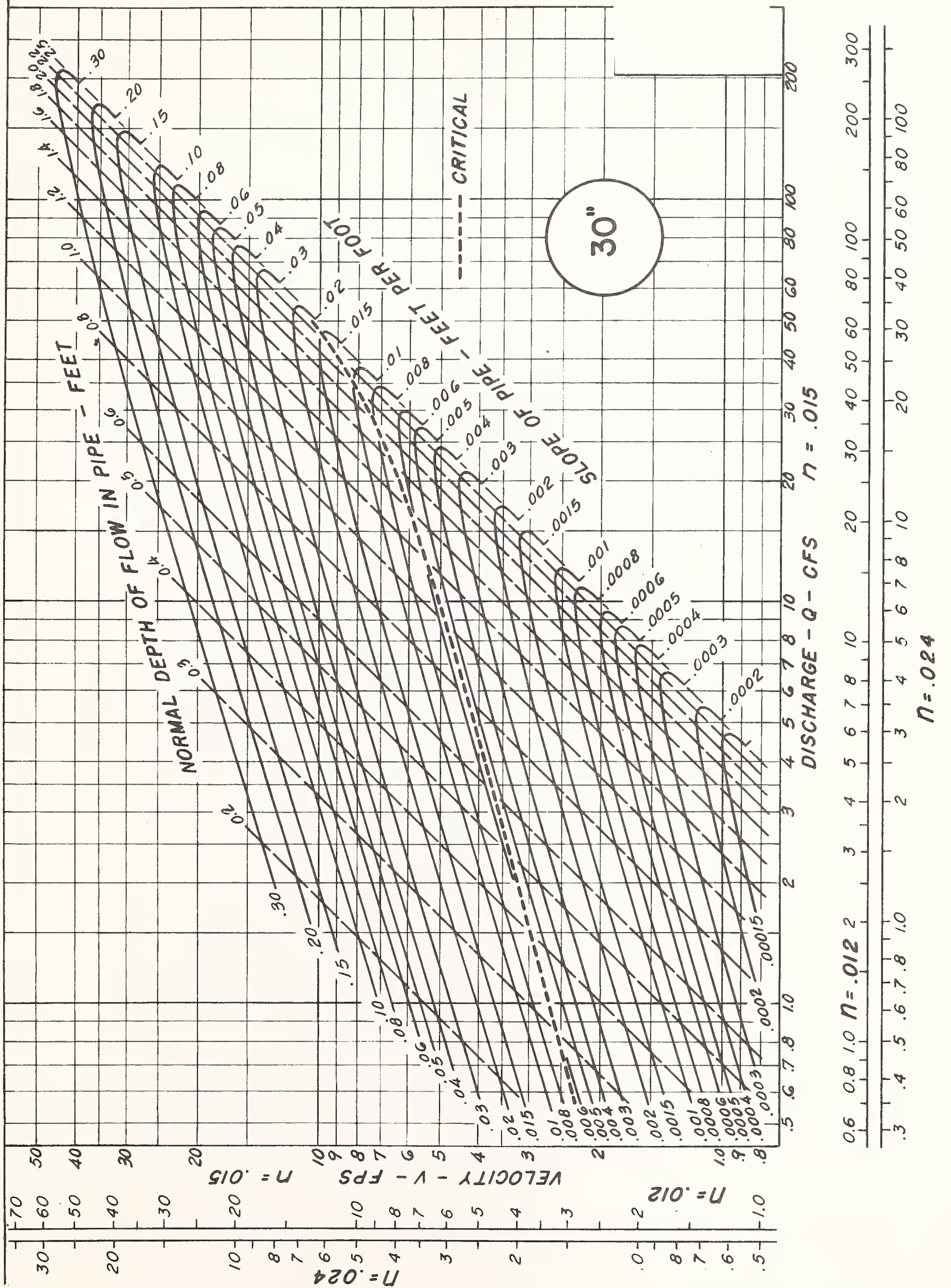
PIPE FLOW CHART
24-INCH DIAMETER

CHART 6



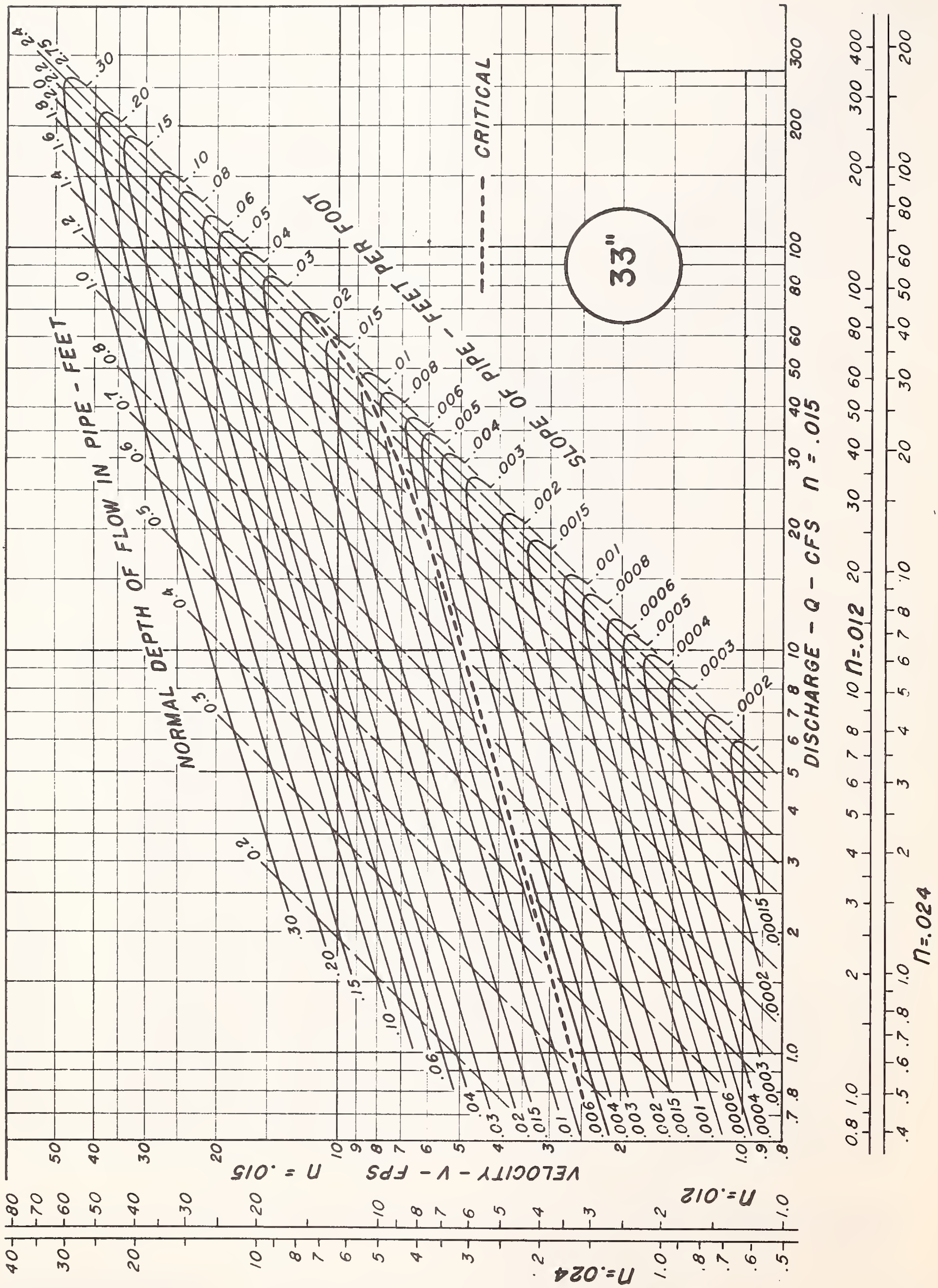
PIPE FLOW CHART
27-INCH DIAMETER

CHART 7



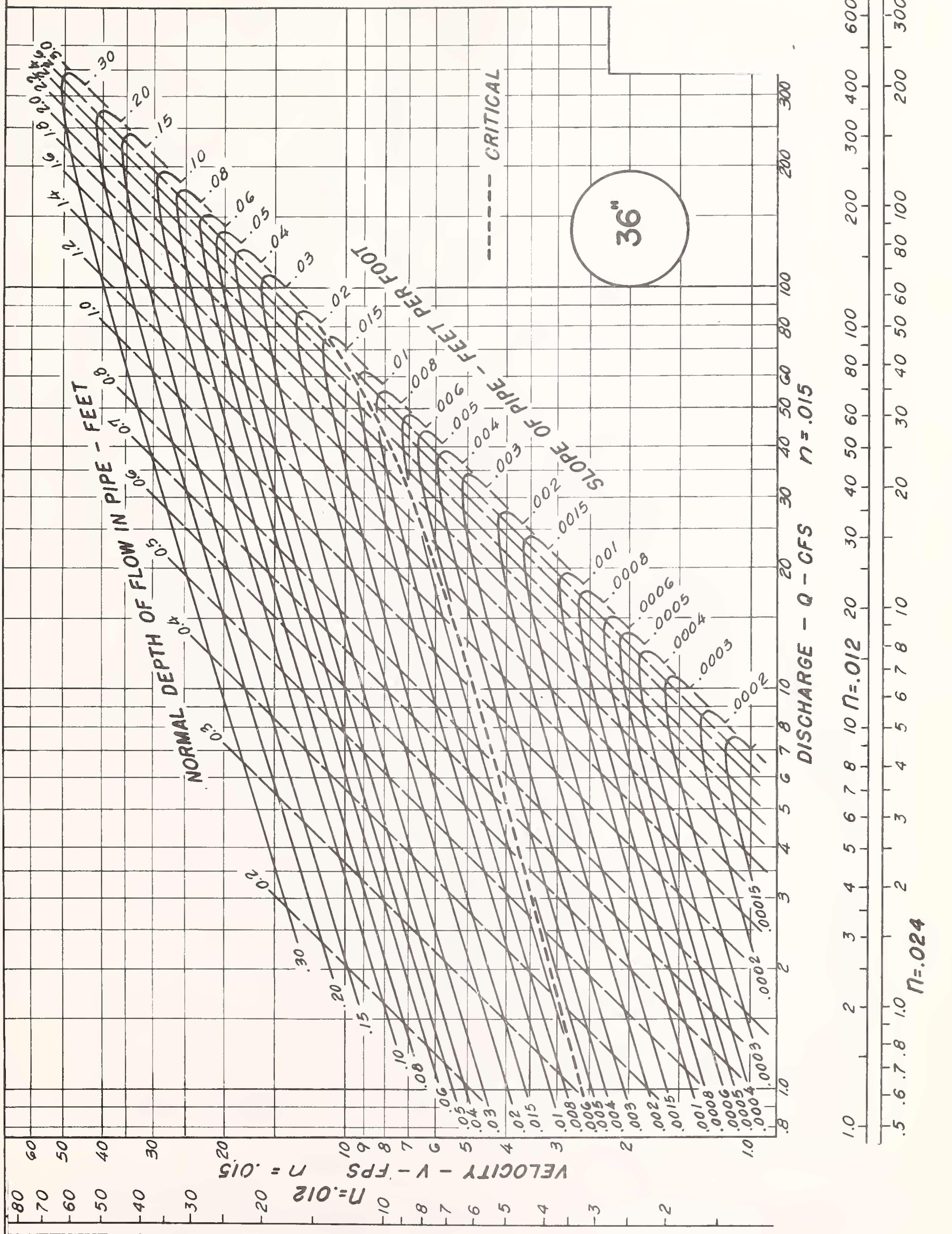
PIPE FLOW CHART
30-INCH DIAMETER

CHART 8



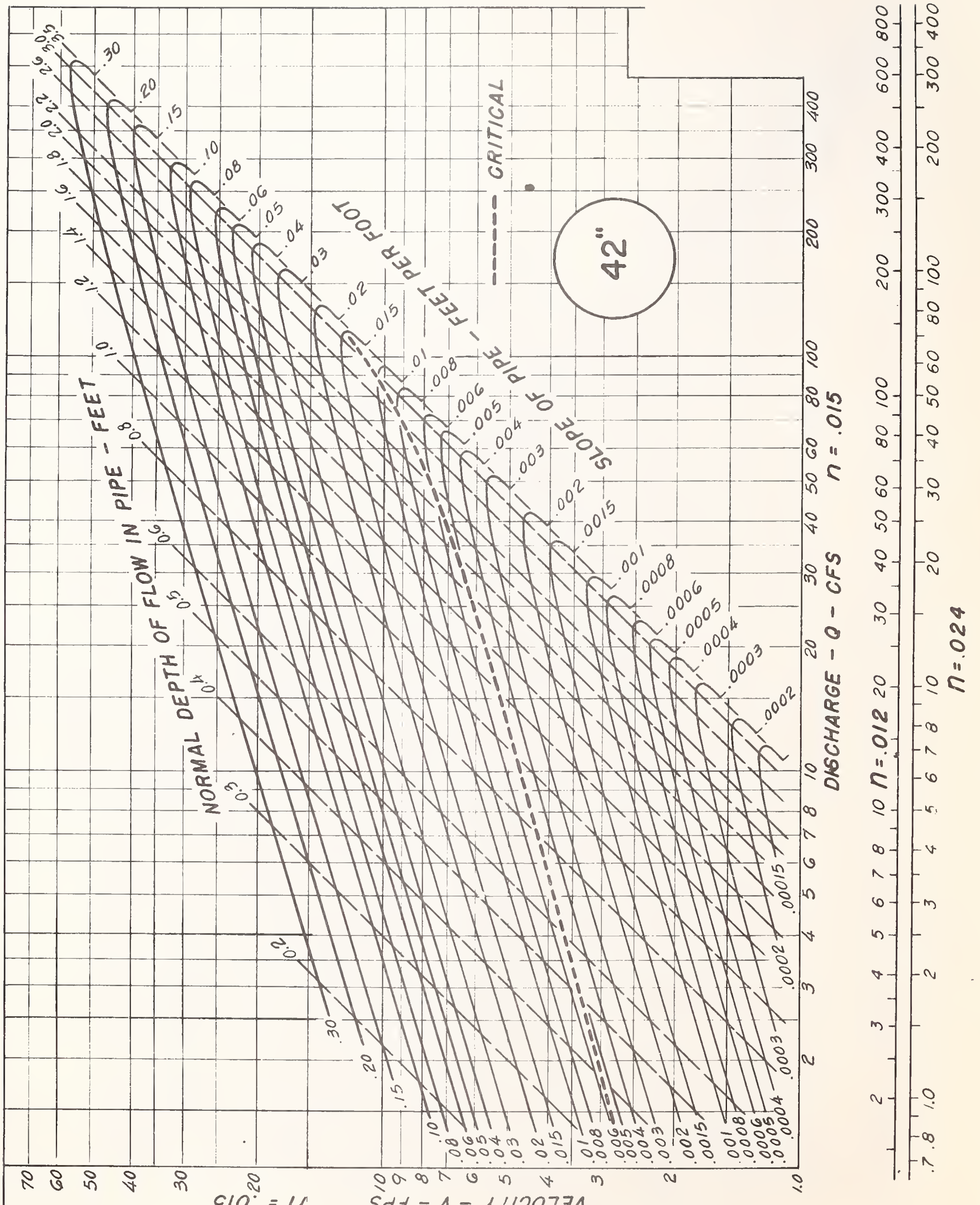
PIPE FLOW CHART
33-INCH DIAMETER

CHART 9



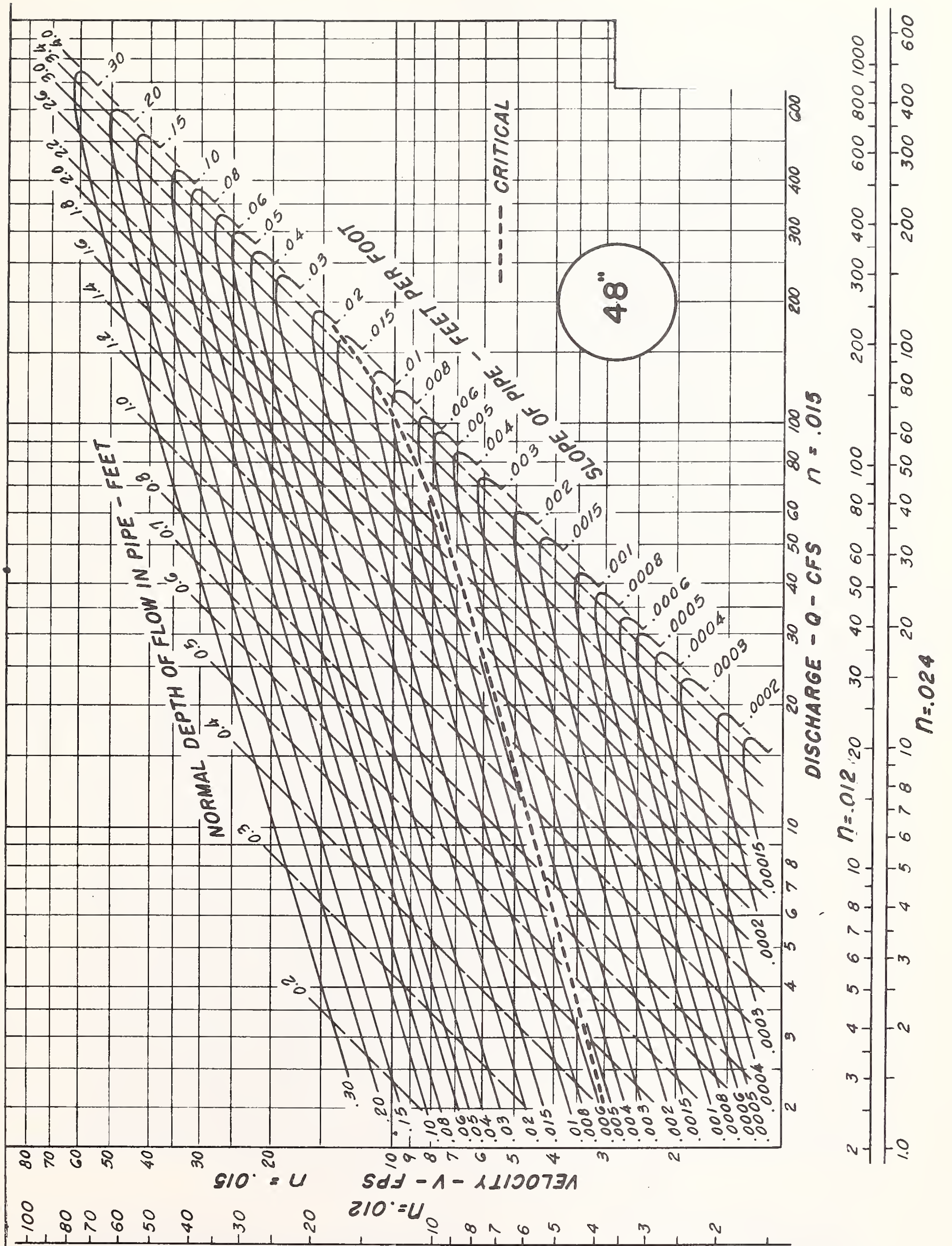
PIPE FLOW CHART
36-INCH DIAMETER

CHART 10



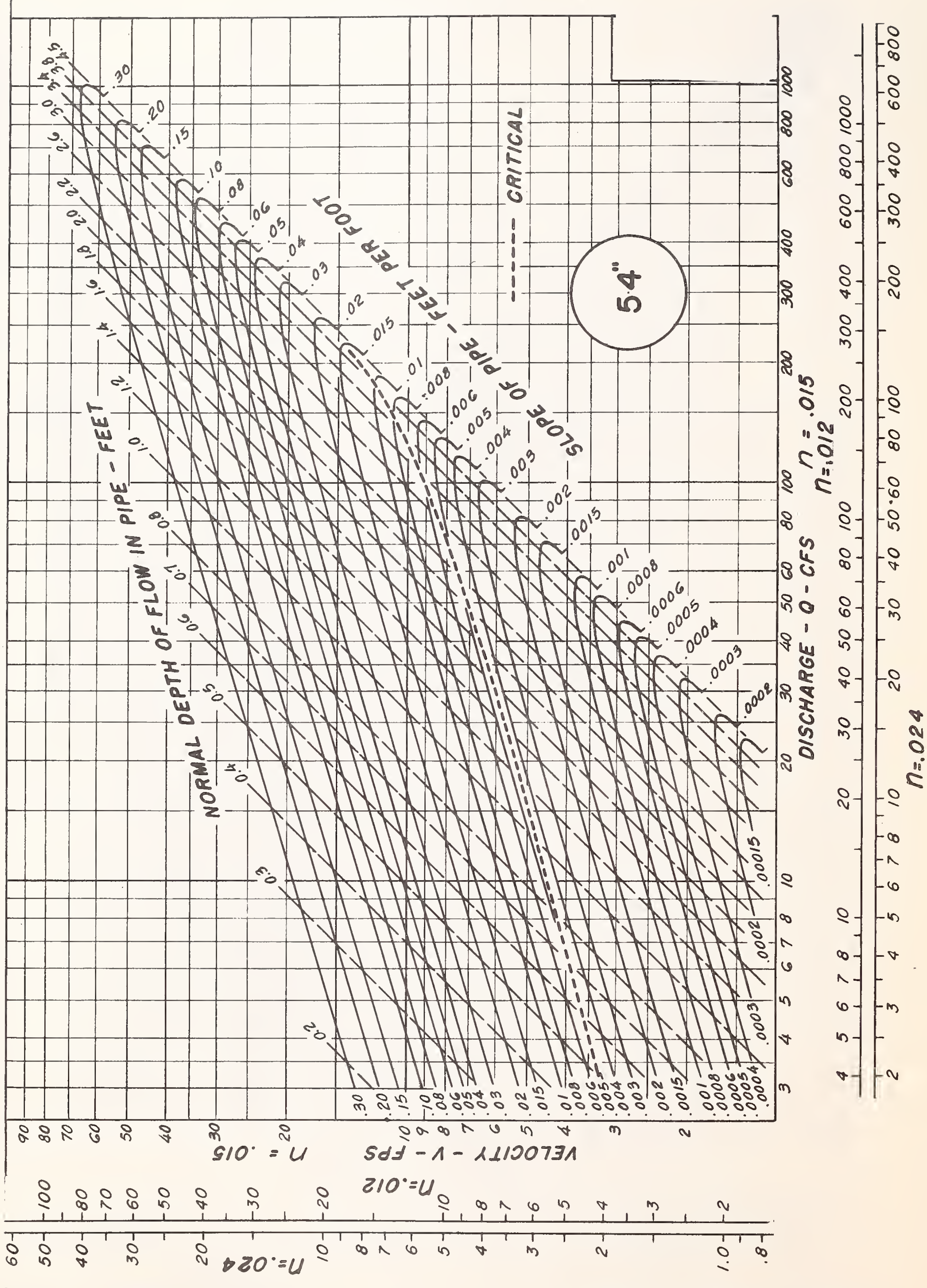
PIPE FLOW CHART
42-INCH DIAMETER

CHART II



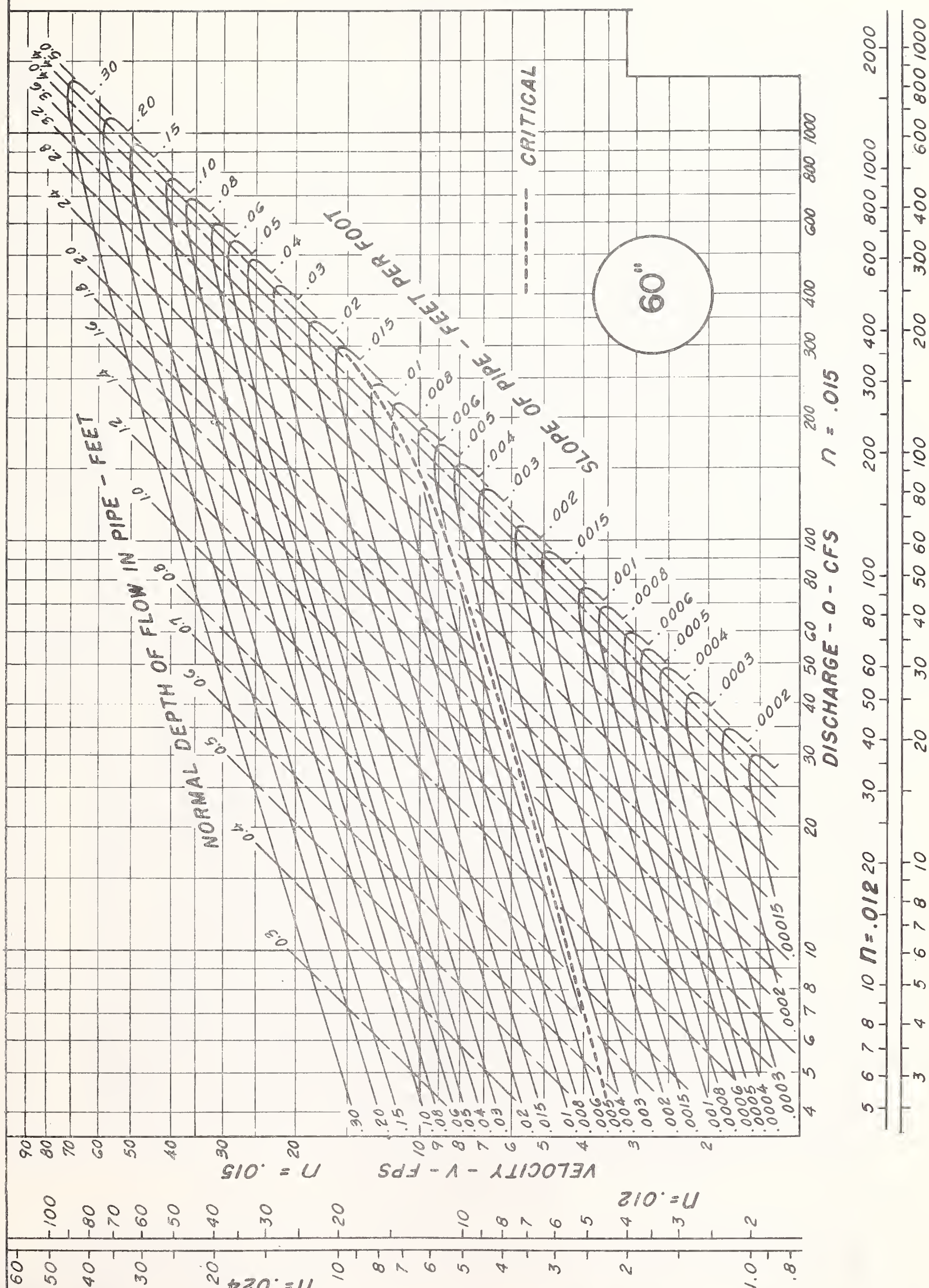
PIPE FLOW CHART
48-INCH DIAMETER

CHART 12



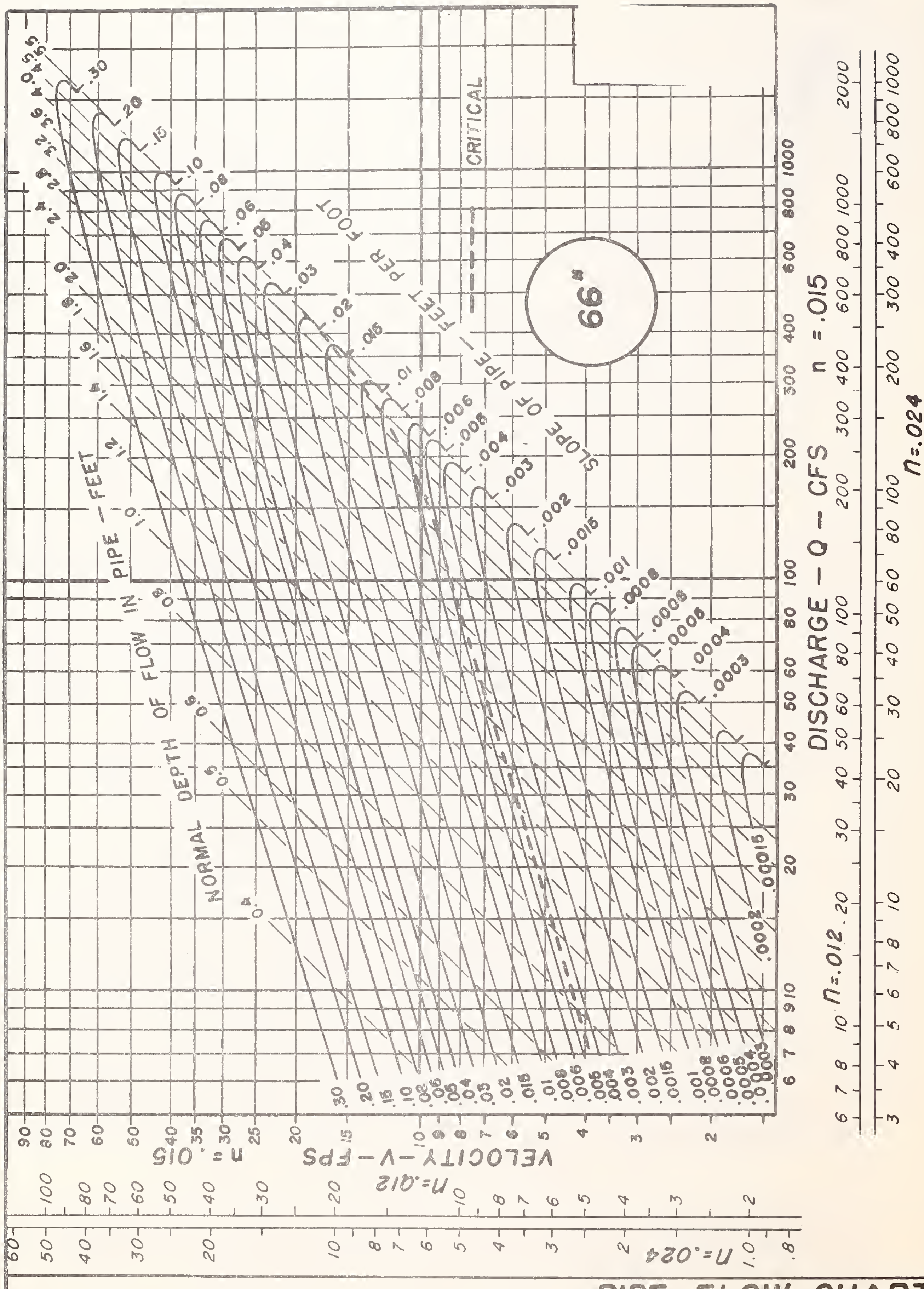
PIPE FLOW CHART
54-INCH DIAMETER

CHART 13



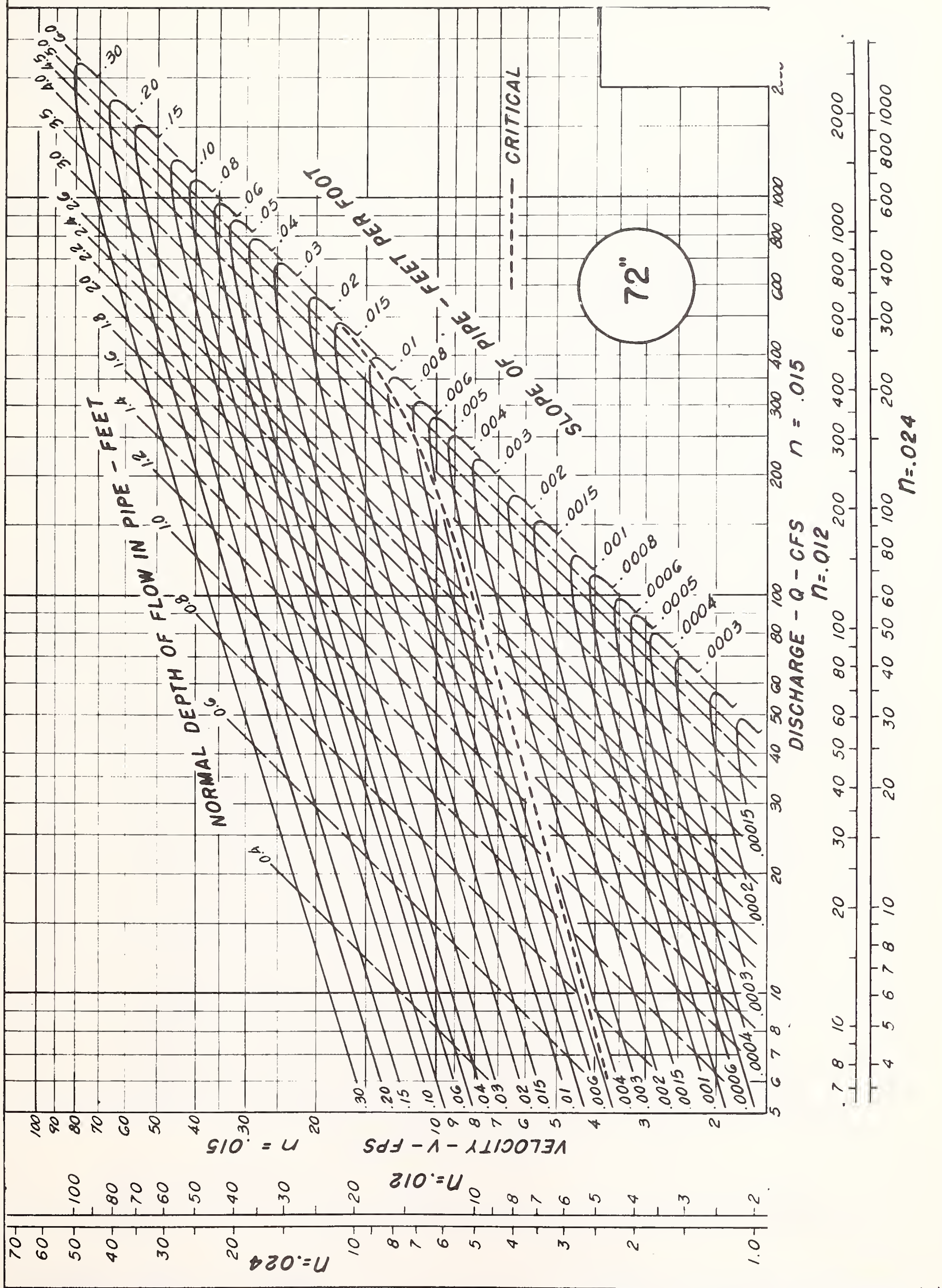
PIPE FLOW CHART
60-INCH DIAMETER

CHART 14



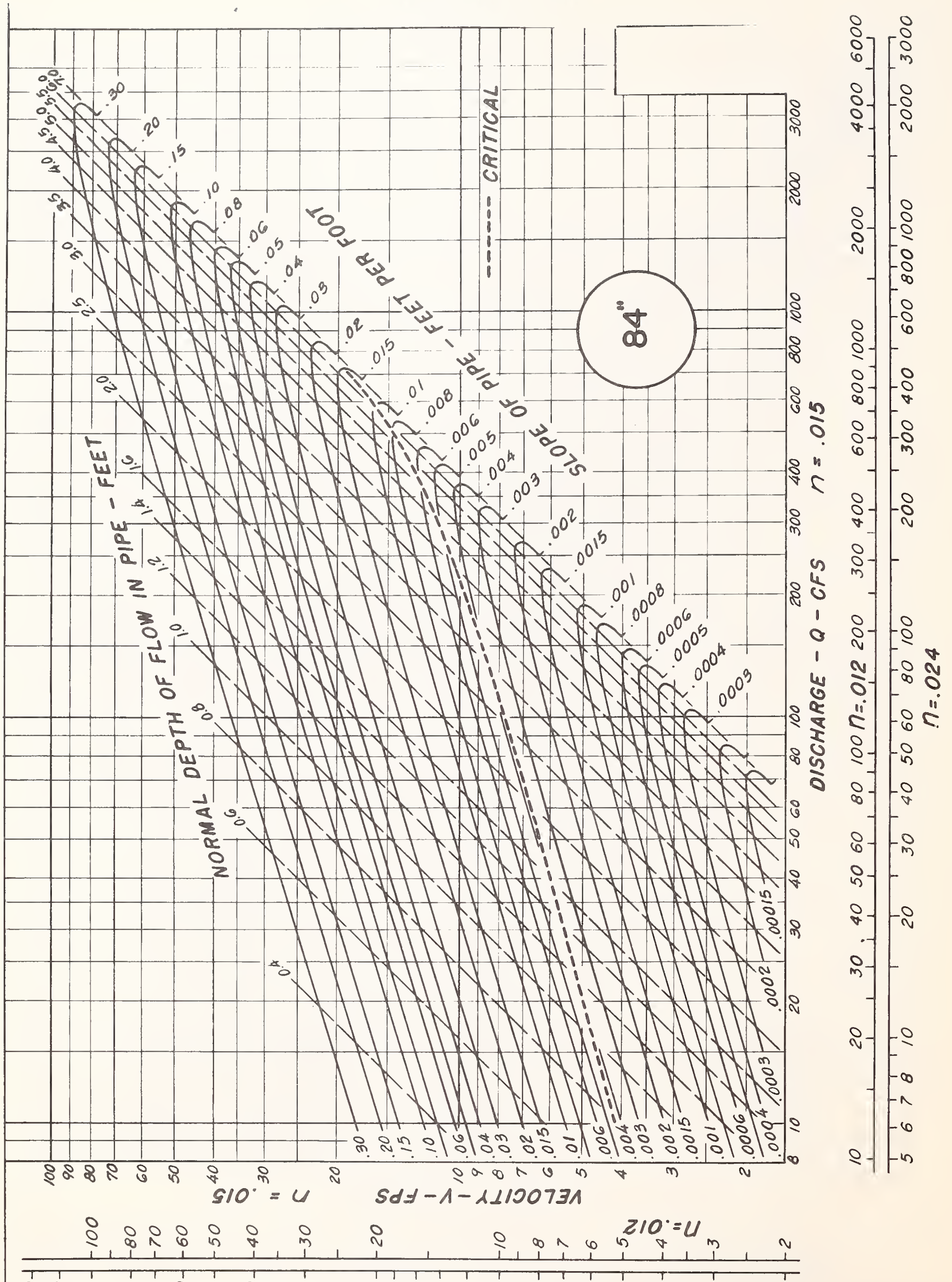
PIPE FLOW CHART
66-INCH DIAMETER

CHART 15



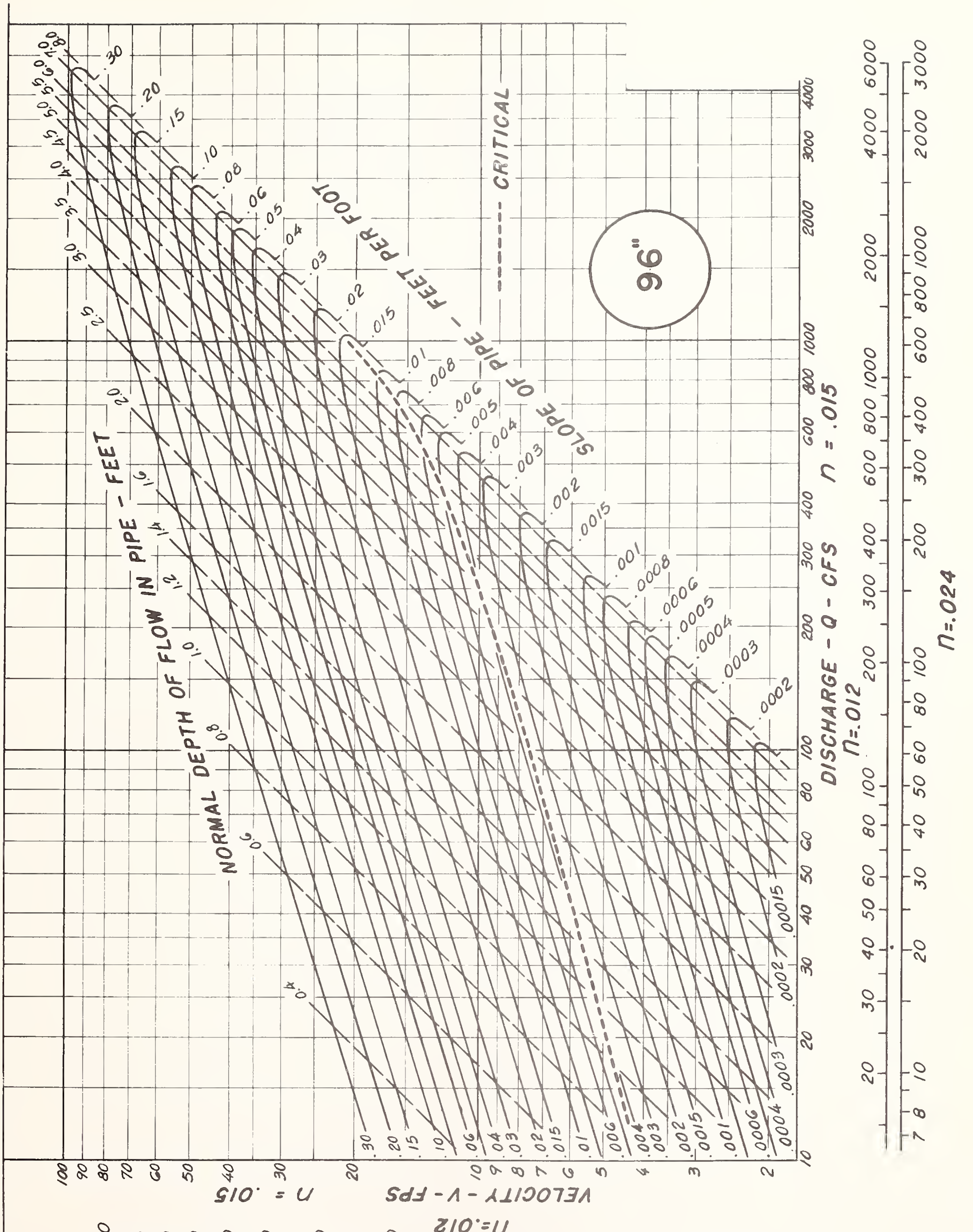
PIPE FLOW CHART
72-INCH DIAMETER

CHART 16



PIPE FLOW CHART 84-INCH DIAMETER

CHART 17



PIPE FLOW CHART
96-INCH DIAMETER

APPENDIX E

CULVERT SELECTION PROCEDURES
PERFORMANCE CHARTS
AND DATA

TABLE OF CONTENTS

PAGE

PROCEDURE FOR DETERMINING REQUIRED CULVERT SIZE 1

Step 1. Data for Culvert Selection 1

Step 2. Determination Headwater for Inlet Control 2

Step 3. Tailwater Determination 2

Step 4. Determination Headwater for Outlet Control 3

Step 5. Control Determination 4

Outlet Velcoity 4

Inlet Control 4

Outlet Control 5

Example 1 6

Example 2 9

Example 3 10

Example 4 12

Exhibit A Sample Design Form 14

Table 1 Mannings n for Culvert Materials 15

Table 2 Entrance Loss Cofficients 16

Culvert Selection Charts 17-30

Critical Depth Charts for Various Cross-sectional Shapes 31-36

PROCEDURE FOR DETERMINING REQUIRED CULVERT SIZE

Charts and tables useful for culvert selection are included as part of this Appendix. They are assembled after the discussion and referred to by Chart or Table number.

The determination of the required size of a culvert of a given type is accomplished by following five basic steps. Exhibit A provides a convenient tabulation sheet for all trial computations from which the final design may be selected. The five steps will be described in detail and numerical examples worked out to illustrate the method. Since the same site is used for all examples, site data is listed here. Several alternate culvert selections are tabulated on Exhibit A, with explanations as required.

Step 1. Determine Data for Culvert Selection

a. Tabulate all site data as follows:

Station Location		Sta 2500 + 75
Roadway Elevation		5131.7
Culvert Inlet Invert Elev.		5112.3
Culvert Outlet Invert Elev.		5111.8
Channel Elev. at Culvert Outlet		5111.8
Culvert Length (approximate)		200 ft
Culvert Slope, $S_o = .5/200 = .0025$	or	.25%

b. Find design discharges (50-year recurrence interval) assuming drainage area is in Flood Region VII.

$$Q_{50} = (6.82)(87.45)A^{.425}\ F^{-.460}$$

Prediction Formula, see Flood Prediction Chart 10, Appendix B.

Drainage Area = 41.0 sq mi

Forest Cover = 27.5%

$$Q_{50} = (6.82)(87.45)(41.0)^{.425}\ (27.5)^{-.460}$$

$$= (596.)(4.85)\left(\frac{1}{4.60}\right) = 627 \text{ cfs (Say 630 cfs by slide rule)}$$

c. Tabulate natural channel data (Field Survey required).

Channel Slope = .0036 = .36%

Channel Condition - perennial stream on prairie, well-defined channel, some weeds and stones, light brush on banks.

Select Manning n = .050 (see Table 2 for Manning n for channels and natural streams - Appendix D).

Allowable headwater AHW = 10.2 ft, based on elevation from crop-land adjacent to channel upstream from culvert.

d. Select type and tenative size culvert.

Determine Manning n for barrel and loss coefficient K_e for type entrance.

Step 2. Determine Headwater HW, for Inlet Control.

a. Refer to Inlet Control Nomographs (Charts 1-7).

Locate desired HW/D ratio on scale (1), (2), or (3) corresponding to type entrance used.

b. Using a straight edge, connect the HW/D ratio with the design discharge and extend the line to intersect the culvert size scale.

c. Select trial culvert size (probably the next commercial size above the point of intersection), extend a straight line from culvert size back through design discharge and read HW/D values. If HW/D is acceptable proceed using trial culvert size.

Step 3. Determine Tailwater Depth, TW

Tailwater elevation is the water elevation in the natural stream channel measured above culvert invert at the design discharge. Tailwater elevation can be determined from high water marks provided such data defines an elevation-discharge rating curve for the stream channel. For a reasonably uniform stream channel tailwater elevation can be calculated as the water surface elevation from the Manning equation with uniform flow assumed.

Step 4. Determine Headwater, HW, ,using Outlet Control

a. Refer to Outlet Control Nomographs (Charts 8-14). Find the starting point on the length scale corresponding to culvert inlet loss coefficient K_e and at the culvert length.

For a K_e value intermediate between the values on the chart, connect the given length of culvert on adjacent scales by a straight line and select starting point on this line spaced between the scales in proportion to K_e.

For a different Manning n, than that shown on the chart use an adjusted culvert length L_1 calculated by

$$L_1 = L \left(\frac{n_1}{n}\right)^2 \tag{2}$$

Using a straight edge connect the starting point on the K_e curve to the culvert barrel dimensions, and mark the crossing point on the turning line. Pivot the straight edge on this crossing point so that it passes through the design discharge, Q. Read the head H on the head scale. H is based on the relation

$$H = \left(1 + K_e + \frac{29n^2L}{R^{1.33}}\right) \frac{V^2}{2g} \tag{3}$$

It is worth noting that Chart 8 for box culverts may be used for full flow for any rectangular box with a span B up to twice the height D, simply by connecting the straight edge to the barrel area shown rather than the box dimensions.

For other box dimensions Chart 8 should not be used, but H may be calculated from Eq (3).

b. Find headwater, HW from the relation

$$HW = h_o + H - S_o L \tag{4}$$

The value of h_o is determined as follows:

(1) If TW is greater than barrel height, D

$$h_o = TW \tag{5}$$

(2) If TW is less than D, h_o is taken as the largest of the values given by Eq. (5) or Eq. (6).

$$h_o = \frac{Y_c + D}{2} \tag{6}$$

Charts 15-20 give critical depth values for most common culvert barrel shapes over all possible discharges. Critical depth for circular culverts up to 96 inch diameter may also be read directly from charts 1-17 in Appendix D. Critical depth cannot exceed D.

Step 5. Control Determination

Determine whether Inlet or Outlet Control occurs and check governing HW against allowable headwater, AHW.

Outlet Velocity

Inlet Control

For Inlet Control the velocity at culvert outlet is taken as the larger of the values corresponding to uniform flow or critical flow at culvert outlet.

The normal depth, Y_n, corresponding to uniform flow for a given Q in a culvert barrel is found by determining the depth of flow which satisfies the Manning equation (Eq. (7)) for this discharge, the barrel cross-section shape, the roughness coefficient and the culvert slope S_o.

$$Q = A \frac{1.49}{n} R^{2/3} S_o^{\ 1/2} \tag{7}$$

For circular pipes values of $AR^{2/3}/D^{8/3}$ vs Y/D are tabulated in Table 3 of Appendix D. From Eq. (7)

$$\frac{AR^{2/3}}{D^{8/3}} = \frac{Q\ n}{1.49\ S_o^{1/2} D^{8/3}} \tag{8}$$

Therefore by calculating the value of the right-hand side of Eq. (8) one can read Y/D from Table 3 and from this calculate Y_n as

$$Y_n = (D)\ (Y/D) \tag{9}$$

Normal depth for flow in circular pipe up to 96 inch diameter can also be read directly from Charts 1-17 in Appendix D. To use these charts first locate the design discharge on the proper scale according to the value of Manning's n. A vertical line is then passed through the design discharge so as to intersect the proper culvert slope curve. This point of intersection defines the normal depth which is read directly from the normal depth scale.

For rectangular culverts values of $AR^{2/3}/B^{8/3}$ vs Y/B are tabulated in Table 4 of Appendix D. Determination of Y_n for a given Q in a box culvert of fixed width B, proceeds in a similar manner.

Critical depth may be determined as discussed under Step 4b.

Outlet Control

For Outlet Control the velocity is determined by the continuity equation

$$V = Q/A \tag{10}$$

where A takes on the value consistent with the determination of the control depth h_o at outlet in Step 4b, as follows:

(1) If TW is greater than the barrel height, D
    A = full culvert barrel cross section

(2) If TW is less than D, but greater than Y_c
    A = culvert barrel cross section corresponding to TW

(3) If TW is less than both D and Y_c
    A = culvert barrel cross section at critical depth, Y_c

Critical depth may be determined as discussed under Step 4b.

When depth of flow is known, the cross sectional area is determined from the barrel geometry. For a rectangular box culvert this computation is obvious while for a circular pipe Table 3 of Appendix D is again convenient. Here values of A/D^2 are tabulated vs Y/D so that A is determined from

$$A = (D^2)\ (A/D^2) \tag{11}$$

The mean velocity at culvert outlet is then simply given by Eq. (10).

Example 1

Try a RCP culvert with end section conforming to fill slope. From Tables 1 and 2, $n = .012$ and $K_e = .5$.

Step 2. Determine HW for Inlet Control

Chart 2 applies to RCP of 12 inch to 180 inch diameter. Since $K_e = .5$, use HW/D scale (1). Try HW/D = 1.20

Lay straight edge from 1.20 on scale (1) through Q = 630 cfs for discharge. This line when extended to the culvert diameter scale reads diam = 104 inch. Select next commercial diam = 108 inch.

For 108 inch diam and Q = 630 cfs a straight edge reads HW/D = 1.12 on scale (1), giving

$$\begin{aligned} HW &= (D)\ (HW/D) \\ &= (108/12)\ (1.12) = 10.08 \text{ ft} \end{aligned}$$

Step 3. Determine Tailwater Depth, TW

Calculation of Y_n from the Manning formula will be used in this example. Assume the cross-sectional area and wetted perimeter of the stream channel at various depths of flow have been determined. Determine normal depth measured above channel elev at culvert outlet (5111.5) by trial and error.

Try Y_n = 5.0 ft

A = 111 sq ft

WP = 32.5 ft

R = A/WP = 111/32.5 = 3.4 ft

n = .050

S_o = .0036 (step 1c)

From a graphical solution of Manning equation, see nomograph Appendix D, mean velocity V = 3.6 ft/sec. Then Q = (V)(A) = (3.6)(111.) = 400 cfs. The computed Q is 100(630-400)/400 or 50% low.

Assume Q varies as Y_n^2

(the exponent on Y_n will vary with shape of cross section)

adjust Y_n by 50/2 = 25%

Try Y_n = (5.0)(1.25) = 6.25 ft

A = 154. sq ft

WP = 45 ft

R = 154/45 = 3.42 ft

From Manning Chart (Appendix D) V = 4.1 ft/sec and Q = (4.1) (154) = 632 cfs.

This is a good check, so Y_n is taken as 6.25 ft.
Culvert invert at outlet is .3 ft above stream bed, so

$$TW = 6.25 - .3 = 5.95 \text{ ft}$$

Step 4. Determine HW for Outlet Control

Chart 9 applies. The starting point is at L = 200 on the K_e = .5 scale. Laying a straight edge from the starting point through a diameter = 108 inches, finding the point on the turning line, and then connecting that point to Q = 630 cfs, gives H = 2.60 ft on the head scale.

From Chart 16 with Q = 630 cfs and D = 9 ft, Y_c is read as 6.20 ft.

TW was calculated in Step 3 as 5.95 ft. Since this is less than D = 9 ft, we compare Eq. (5) and Eq. (6).

From Eq. (5) $h_o = 5.95$ ft

From Eq. (6) $h_o = (\frac{6.2 + 9}{2}) = 7.60$ ft

The larger value, $h_o = 7.60$ ft applies.

From Eq. (4) $HW = 7.60 + 2.60 - (.0025)\ (200)$

$= 7.60 + 2.60 - .5 = 9.70$ ft

Step 5. Determine whether Inlet or Outlet Control occurs and whether Trial Culvert Size is Satisfactory.

From Step 2 Inlet-Control HW = 10.08 ft

From Step 4 Outlet-Control HW = 9.70 ft

Therefore the 9 ft diameter RCP culvert flows with Inlet-Control and the required headwater is 10.08 ft.

Since the allowable headwater, AHW = 10.2 ft, the size is sufficient to pass the 630 cfs 50-year recurrence interval flood.

Outlet Velocity

Calculate outlet velocity based on Inlet-Control.

Pertinent data is:

$Q = 630$ cfs

$D = 9$ ft (circular culvert barrel)

$S_o = .0025$ ft/ft

$n = .012$

Determine Y_n:

$$\frac{AR^{2/3}}{D^{8/3}} = \frac{Qn}{1.49\ S_o^{1/2} D^{8/3}} = \frac{(630)\ (.012)}{(1.49)\ (.0025)^{1/2} (9)^{8/3}} = \frac{5.08}{(.05)\ (353)} = .288$$

From Table 3, Appendix D a value of $\frac{AR^{2/3}}{D^{8/3}} = .288$ corresponds to $\frac{Y_n}{D} = .76$.

Therefore

$$Y_n = D\left(\frac{Y_n}{D}\right) = (9)\ (.76) = 6.84 \text{ ft}$$

Determine Y_c: From Step 4b.

$$Y_c = 6.20 \text{ ft}$$

Since Y_c is less than Y_n calculate outlet velocity assuming Y_c exists at outlet.

From Table 3 Appendix D for $Y_c/D = 6.20/9 = .667$ it is found that $A_c/D^2 = .5552$

therefore

$$A_c = (9)^2(.5552) = 45.0 \text{ sq ft}$$
$$V_c = 630/45.0 = 14.0 \text{ ft/sec}$$

A velocity of 14.0 ft/sec is too high to discharge into the natural stream channel. An energy dissipating structure and/or properly designed channel protection will be required.

All data summarizing the 9 ft RCP culvert selection, performing with Inlet Control and HW = 10.08 ft, is listed on Exhibit A, the Culvert Design sheet.

Example 2

Select a 108 inch corrugated metal (C.M.) culvert with square-edge head wall. Tables 1 and 2 show Manning n = .024 and $K_e = .5$.

From Chart 5 for Inlet Control on scale (1) HW/D = 1.08, so

$$HW = (1.08)(9) = 9.72 \text{ ft}$$

From Chart 11 for Outlet Control (L = 200 ft) H = 4.00 ft. As before h_o is 7.60 ft and HW is

$$HW = 7.60 + 4.00 - .50 = 11.10 \text{ ft}$$

We see that with the CM pipe, due to the additional barrel roughness, outlet control governs. Outlet velocity will be the same as for the 108 inch RCP since it is calculated at the same critical depth, 6.20 ft.

Example 3

Select a 10 ft span box culvert with headwall parallel to embankment for the same site. For this inlet Table 2 shows $K_e = .50$. To illustrate the effect of an n value different than on the chart assume n = .013 and L = 200 ft. Recall that Q = 630 cfs.

Step 2 Inlet Control

Chart 1 applies. Calculate Q/B = 630/10 = 63 cfs/ft. Use scale (2). A box culvert with 7 ft D and 10 ft B requires HW/D = 1.24.

$$HW = 7 \times 1.24 = 8.68 \text{ ft}$$

Step 3 Same as before. TW = 5.95 ft

Step 4 Outlet Control. See Chart 8.

Calculate equivalent length.

$$L_1 = L\left(\frac{n_1}{n}\right)^2 = 200\left(\frac{.013}{.012}\right)^2 = 235. \text{ ft}$$

Determine H.

The starting point is located at L = 235 on the $K_e = .5$ scale. The 10 ft x 7 ft box culvert has a cross section area = 70 sq ft. From Chart 8, H is read as 2.40 ft.

Find headwater, HW.

TW = 5.95 ft
D = 7.00 ft

From above TW is less than D.

For a rectangular section critical depth may be calculated direct.

$$Y_c = {}^{3}\ 63.^{2}/32.2 = 4.96 \text{ ft}$$

Chart 15 with Q/B = 63. checks this value. Outlet control depth will be

$$h_o = \frac{Y_c + D}{2} = \frac{11.96}{2} = 5.98 \text{ ft}$$

Since this exceeds TW.

Then

$$\begin{aligned} HW &= h_o + H - S_oL \\ &= 5.98 + 2.40 - .5 = 7.88 \text{ ft} \end{aligned}$$

(note S_oL is taken as .50, as before)

Therefore Inlet Control also governs the performance of this culvert and HW = 8.68 ft, which is less than AHW = 10.2 ft.

Outlet Velocity

For outlet velocity for Inlet Control flow is that at normal or critical depth, whichever is greater. To find Y_n for a rectangular cross section see Table 4 of Appendix D.

$$\frac{Qn}{S_o^{1/2}B^{8/3}} = \frac{630 \text{ x } .013}{(.0025)^{1/2}(10)^{8/3}} = .356$$

From Table 4 Appendix D

$$\frac{Qn}{S_o^{1/2}B^{8/3}} = .356 \text{ corresponds to } \frac{Y_n}{B} = .58$$

therefore $Y_n = 10(.58) = 5.8$ ft

Y_c has been determined as 4.96 ft, which is less than Y_n. Therefore $A_c = (4.96)(10) = 49.6$ sq ft and the outlet velocity is

$$V_c = \frac{630}{49.6} = 12.7 \text{ ft/sec}$$

Again the outlet velocity is excessive and requires an energy dissipating structure and/or properly design channel protection.

Example 4

To illustrate the use of the Outlet Control equations where the charts do not apply, suppose the 7 ft x 10 ft box culvert was 600 ft long but placed with a 1.00 ft total drop so that the invert slope is only 1/600 = .00167. Suppose Manning n = .015 and K_e = .5. Chart 8 does not show L values over 500 ft, so we use Eq. (3).

$$H = (1 + K_e + \frac{29n^2L}{R^{1.33}}) \frac{V^2}{2g} \tag{3}$$

Here $V = 630/70 = 9.0$ ft/sec so $V^2/2g = 1.26$ ft. Now $R = A/WD = 70/34 = 2.06$ ft and $R^{1.33} = 2.62$ ft. Therefore

$$H = 1.5 + \frac{(29)(.015)^2(600)}{2.62} \; 1.26 = (2.99)(1.26) = 3.77 \text{ ft}$$

With $S_oL = 1.00$ ft

$$HW = 5.98 + 3.77 - 1.00 = 8.75 \text{ ft}$$

Since for Inlet Control HW = 8.68 ft, Outlet Control now barely governs. This example illustrates that the value of H calculated for Outlet Control does not change as much with a change in culvert length as one might have thought. (Recall that H for L = 200 ft and n = .013 was 2.40 ft in Ex. 3)

Outlet Velocity

For Outlet Control, the velocity is calculated as follows. TW = 5.95 ft, D = 7.00 ft, $Y_c = 4.96$ ft. Outlet velocity is therefore found using the barrel area corresponding to TW, giving

$$V = \frac{630}{59.5} = 10.6 \text{ ft/sec}$$

This too is an excessive velocity, requiring special outlet protection. The alternate selection results are listed on the Culvert Design sheet.

PROJECT: ______________

DESIGNER: ______________

DATE: ______________

HYDROLOGIC AND CHANNEL INFORMATION

FLOOD REGION VII SOUTHEAST

DRAINAGE AREA 41.0 sq mi

OTHER DRAINAGE AREA CHARACTERISTICS

F = 27.5%

Q_1 = 630 cps TW_1 = 5.95

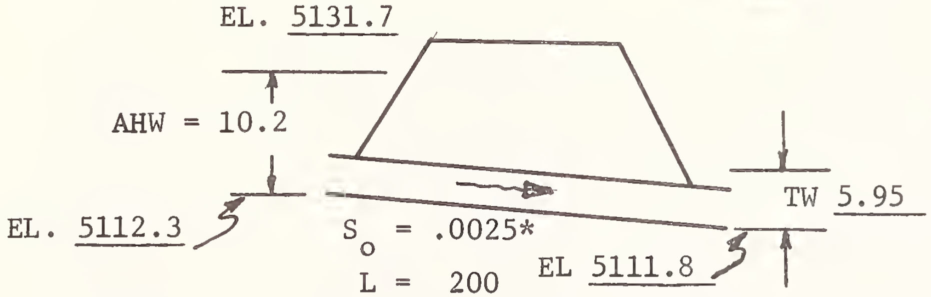
Q_2 = ______ TW_2 = ______

CHANNEL = SLOPE = .0036 n = .050

MAX ALLOW VEL. 5.0

SKETCH

STATION: 2500+75



AHW: BASED ON CROP-LAND @ EL 114.3

TW : BASED ON OUTLET CHANNEL

No	Culvert Description (Entrance type)	Q	Size	HEADWATER COMPUTATION										Controlling HW	Outlet Velocity	Comments
				Inlet Cont.		Outlet Control HW = H + h_o − LS_o										
				$\frac{HW}{D}$	HW	K_e	H	d_c	$\frac{d_c+D}{2}$	TW	h_o	LS_o	HW			
1.	RCP MITRE END	630	108	1.12	10.08	.5	2.60	6.20	7.60	5.95	7.60	.50	9.70	10.08	14.0	CHANNEL PROTECT REQ'D-V TOO HIGH
2.	CMP SQ. HD WALL	630	108	1.08	9.72	.5	4.00	6.20	7.60	5.95	7.60	.50	11.10	11.10	14.0	" "
3.	10' SPAN BOX HD WALL//EM	630	10 x 7	1.24	8.68	.5	2.40	4.96	5.98	5.95	5.98	.50	7.88	8.68	12.7	" "
4.	10' SPAN BOX HD WALL//EM	630	10 x 7	1.24	8.68	.5	3.77	4.96	5.98	5.95	5.98	1.00	8.75	8.75	10.6	" "
	*NOTE L = 600' S_o = .00167 IN 4TH CASE AND INVERT = 5111.8 AT OUTLET															

SUMMARY & RECOMMENDATIONS:

In-place cost, availability, location, cover requirements, etc., should be considered by the designer in selecting culvert. CM pipe arch culverts or concrete oval pipes might be a solution where cover is limited.

Exhibit A Sample Culvert Design Sheet

Table 1

Manning's n for Culvert Materials

Material	n		
Concrete Pipe	.012		
Concrete Box	.012		
Corrugated Metal	Small Corrugations (2 2/3" x 1/2")	Medium Corrugations (3" x 1")	Large Corrugations (6" x 2")
Unpaved	.024	.027	.030-.033*
25% Paved	.021	.023	.026
50% Paved	.018	.019	.020
Fully Paved	.012	.012	.012

*for pipe-arch from 6.1 ft x 4.6 ft to 16.6 ft x 10.1 ft in size. (smaller n value for larger pipe-arch)

TABLE 2

Entrance Loss Coefficients

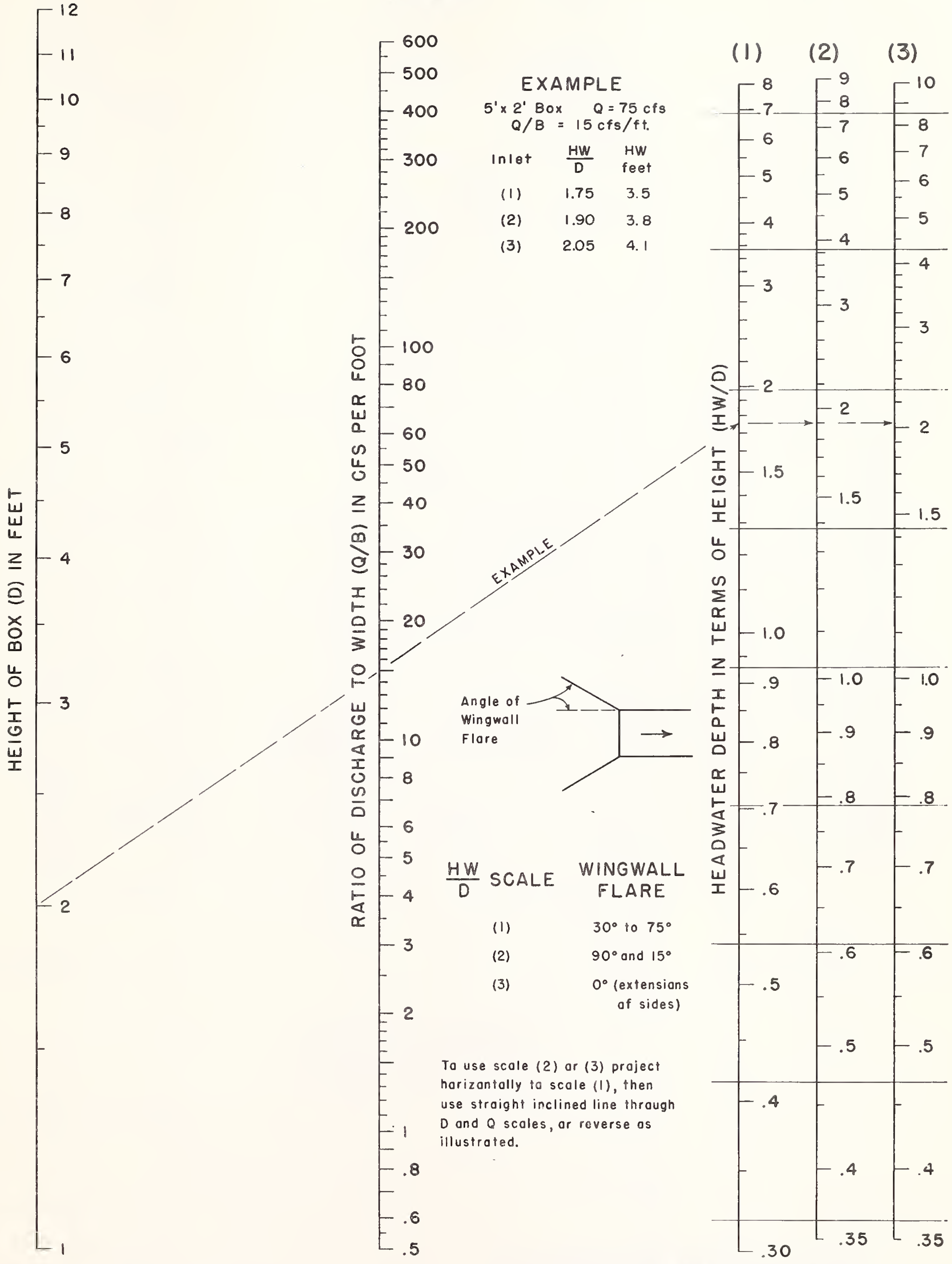
Coefficient K_e to apply to velocity head $\frac{V^2}{2g}$ to determine loss of head at entrance to a structure, such as a culvert or conduit, operating full or partly full with control at the outlet.

$$\text{Entrance head loss } H_e = K_e \frac{V^2}{2g}$$

Type of Structure and Design of Entrance	Coefficient K_e
Pipe, Concrete	
Projecting from fill, socket end	0.2
Projecting from fill, sq cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe	0.2
Square edge	0.5
Rounded (radius = 1/12 D)	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope (Apron)	0.5
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls	
Square-edge	0.5
Mitered to conform to fill slope	0.7
*End-section conforming to fill slope (Apron)	0.5
Box, Reinforced Concrete	
Headwall parallel to embankment	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension	0.2
Wingwalls at 30° to 75° to barrel	
Square-edge at crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension	0.2
Wingwalls at 10° to 30° barrel	
Square-edge at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7

*Note: "End Section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control.

CHART 1



EXAMPLE

5' x 2' Box Q = 75 cfs
Q/B = 15 cfs/ft.

Inlet	$\frac{HW}{D}$	HW feet
(1)	1.75	3.5
(2)	1.90	3.8
(3)	2.05	4.1

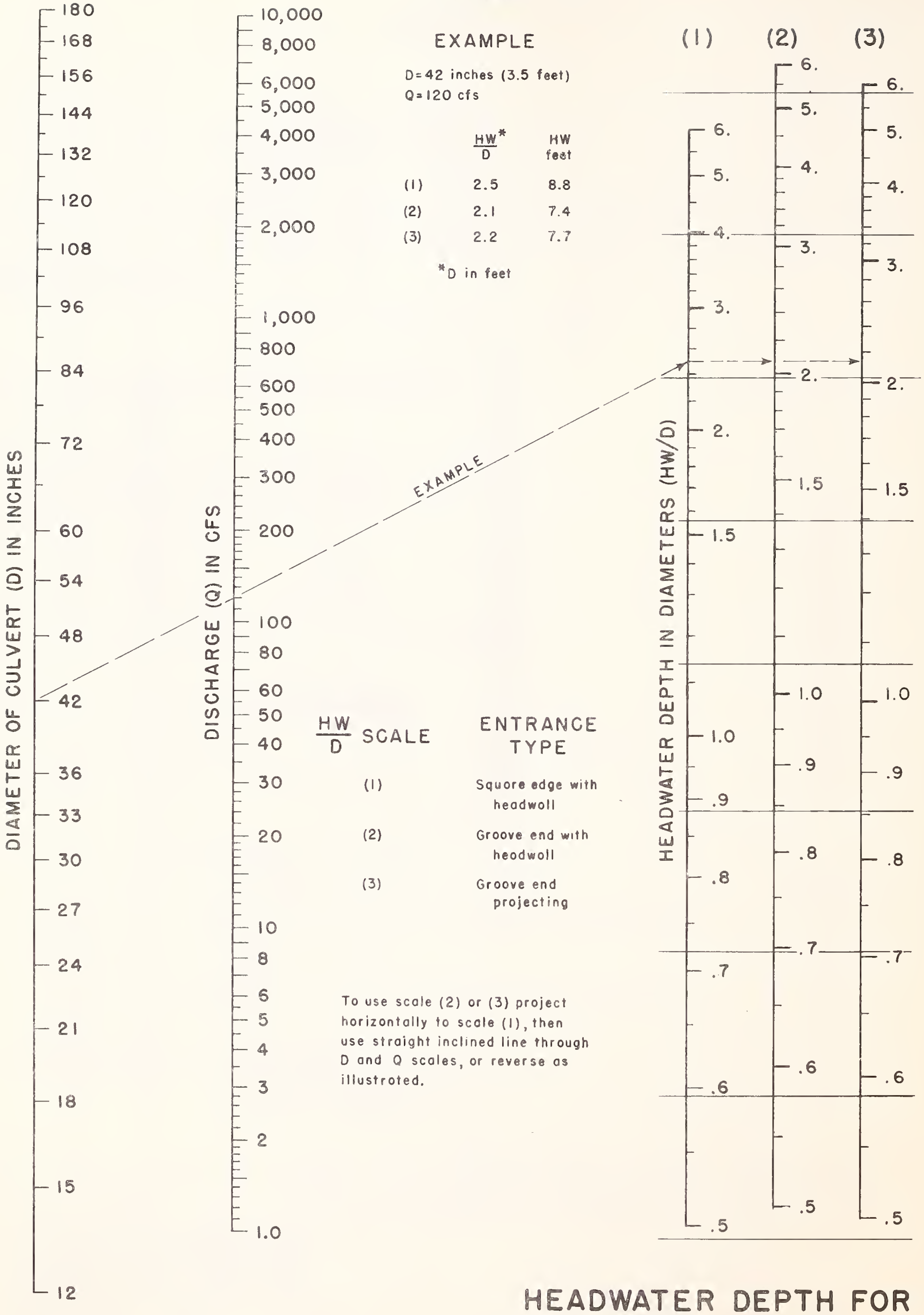
$\frac{HW}{D}$ SCALE	WINGWALL FLARE
(1)	30° to 75°
(2)	90° and 15°
(3)	0° (extensions of sides)

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 2



EXAMPLE

D=42 inches (3.5 feet)
Q=120 cfs

	$\frac{HW}{D}$*	HW feet
(1)	2.5	8.8
(2)	2.1	7.4
(3)	2.2	7.7

*D in feet

$\frac{HW}{D}$ SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

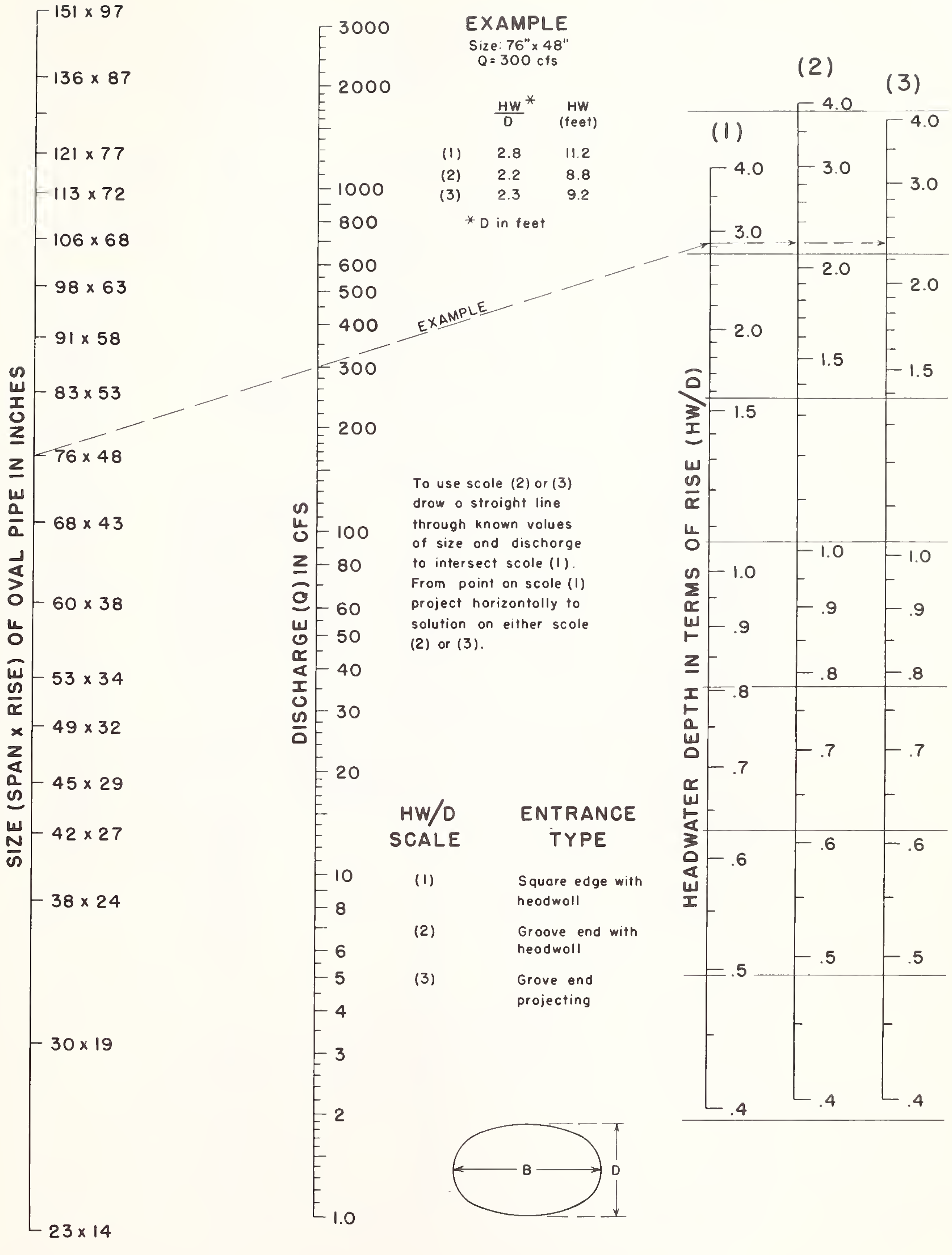
To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

HEADWATER SCALES 2&3
REVISED MAY 1964

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 3



EXAMPLE

Size: 76"x 48"
Q= 300 cfs

	$\frac{HW}{D}$*	HW (feet)
(1)	2.8	11.2
(2)	2.2	8.8
(3)	2.3	9.2

*D in feet

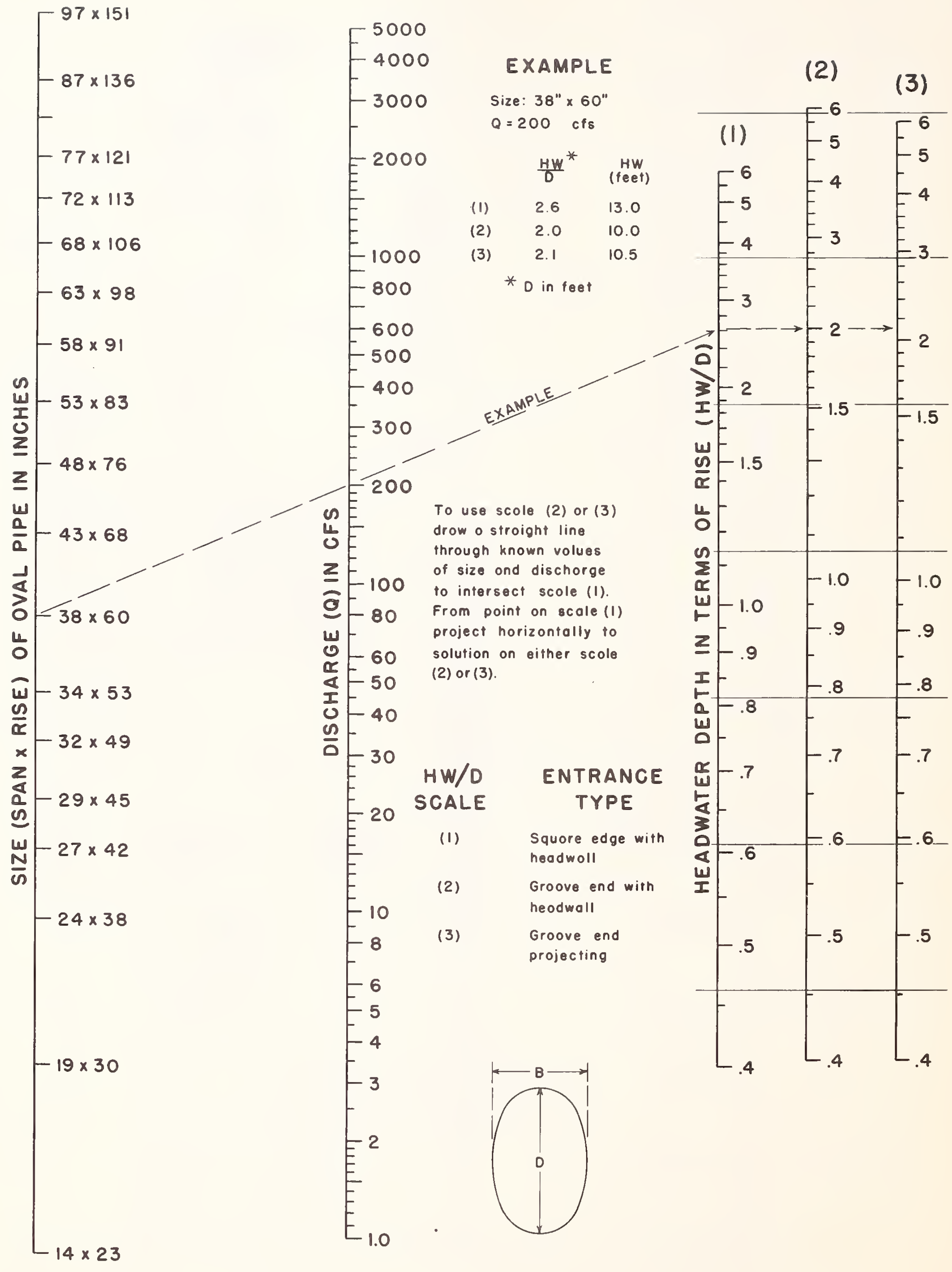
To use scale (2) or (3) draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1) project horizontally to solution on either scale (2) or (3).

HW/D SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Grove end projecting

HEADWATER DEPTH FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS HORIZONTAL WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 4



EXAMPLE

Size: 38" x 60"
Q = 200 cfs

	$\frac{HW}{D}$*	HW (feet)
(1)	2.6	13.0
(2)	2.0	10.0
(3)	2.1	10.5

* D in feet

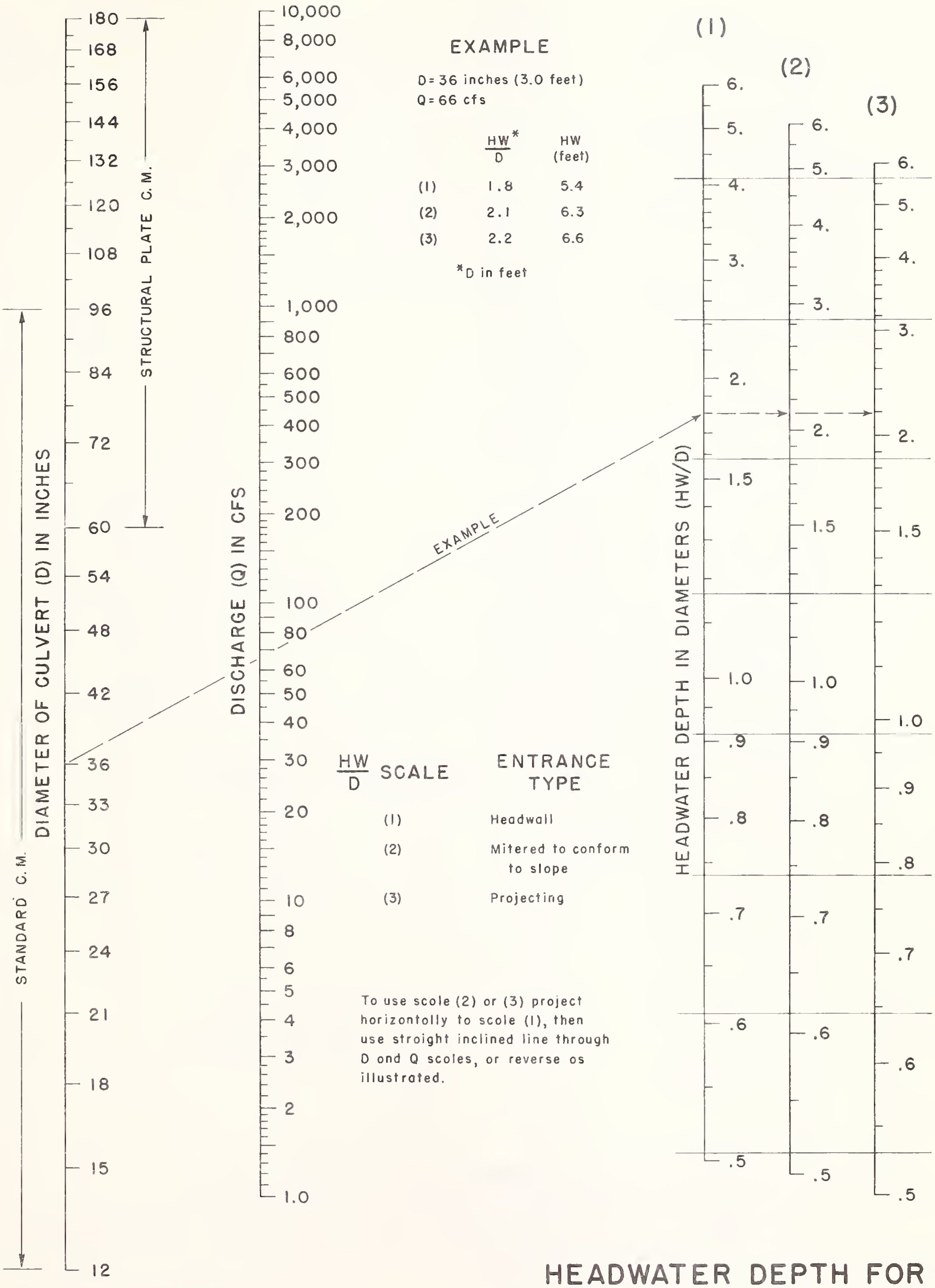
To use scale (2) or (3) draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1) project horizontally to solution on either scale (2) or (3).

HW/D SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

HEADWATER DEPTH FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS VERTICAL WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 5



EXAMPLE

D = 36 inches (3.0 feet)
Q = 66 cfs

	$\frac{HW}{D}$*	HW (feet)
(1)	1.8	5.4
(2)	2.1	6.3
(3)	2.2	6.6

*D in feet

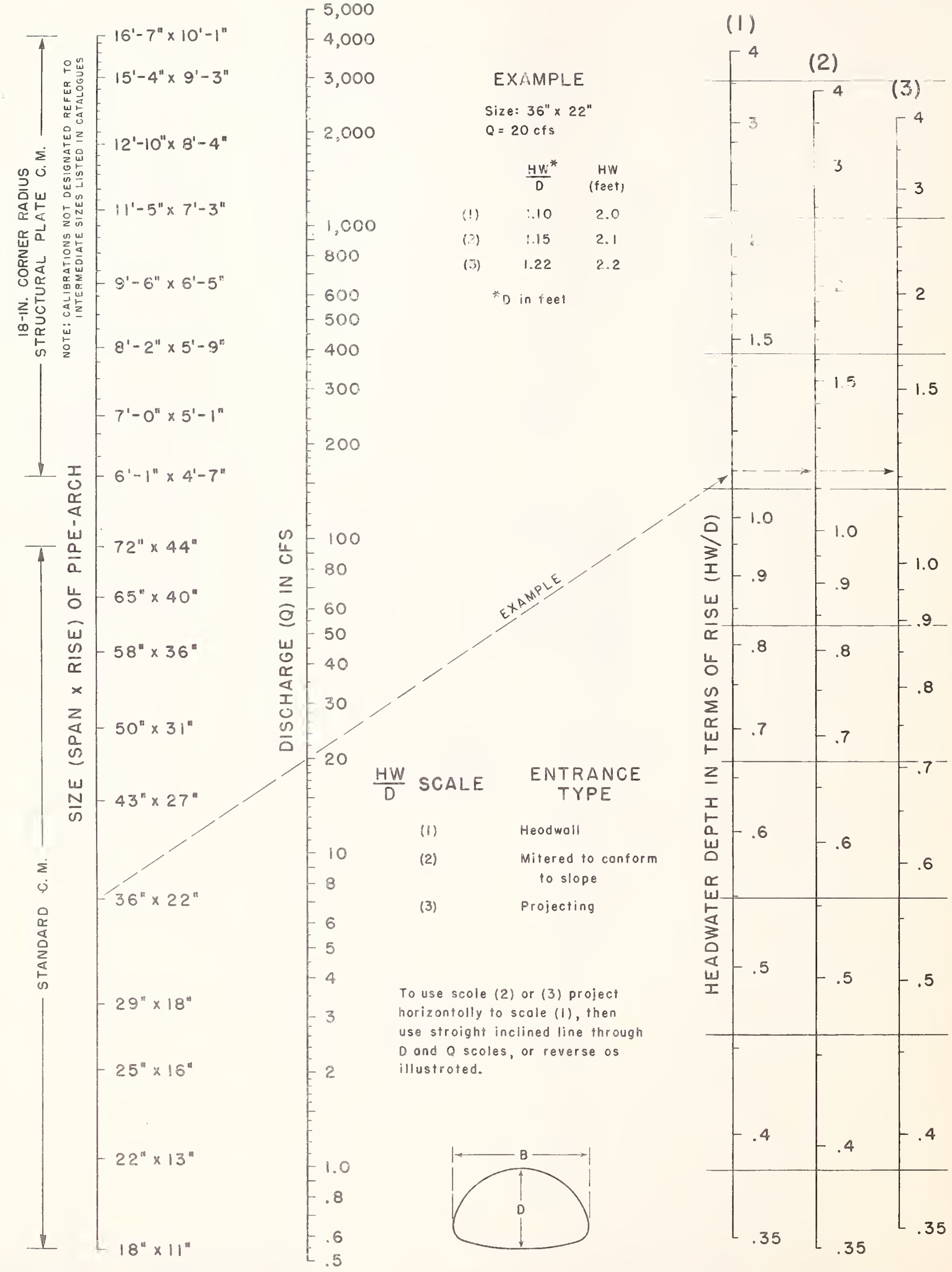
$\frac{HW}{D}$ SCALE	ENTRANCE TYPE
(1)	Headwall
(2)	Mitered to conform to slope
(3)	Projecting

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

HEADWATER DEPTH FOR C. M. PIPE CULVERTS WITH INLET CONTROL

Fig. 20 Sample Design Chart for Inlet Control

CHART 6



EXAMPLE

Size: 36" x 22"
Q = 20 cfs

	$\frac{HW}{D}$*	HW (feet)
(1)	1.10	2.0
(2)	1.15	2.1
(3)	1.22	2.2

*D in feet

$\frac{HW}{D}$ SCALE	ENTRANCE TYPE
(1)	Headwall
(2)	Mitered to conform to slope
(3)	Projecting

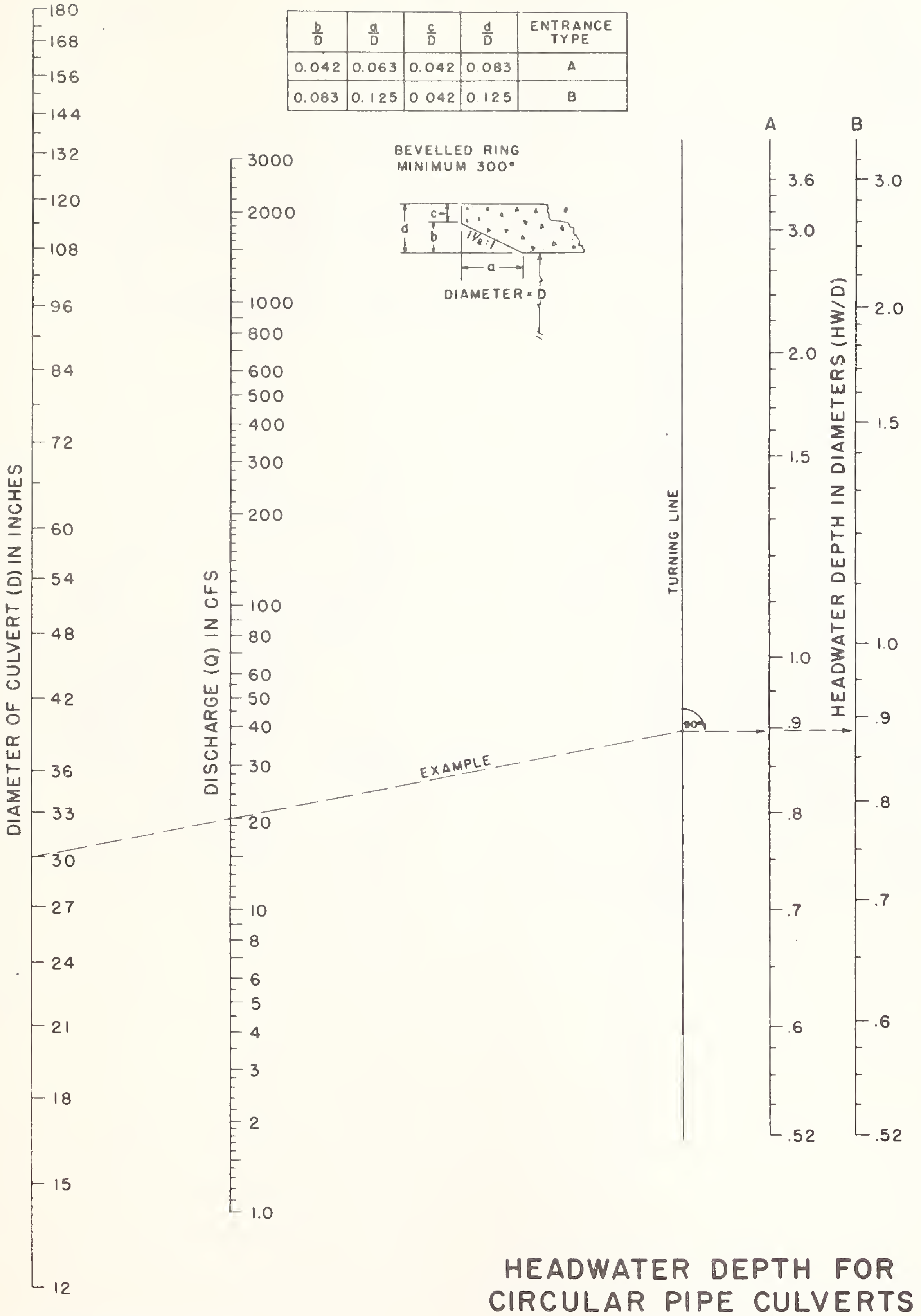
To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

HEADWATER DEPTH FOR C. M. PIPE-ARCH CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 7

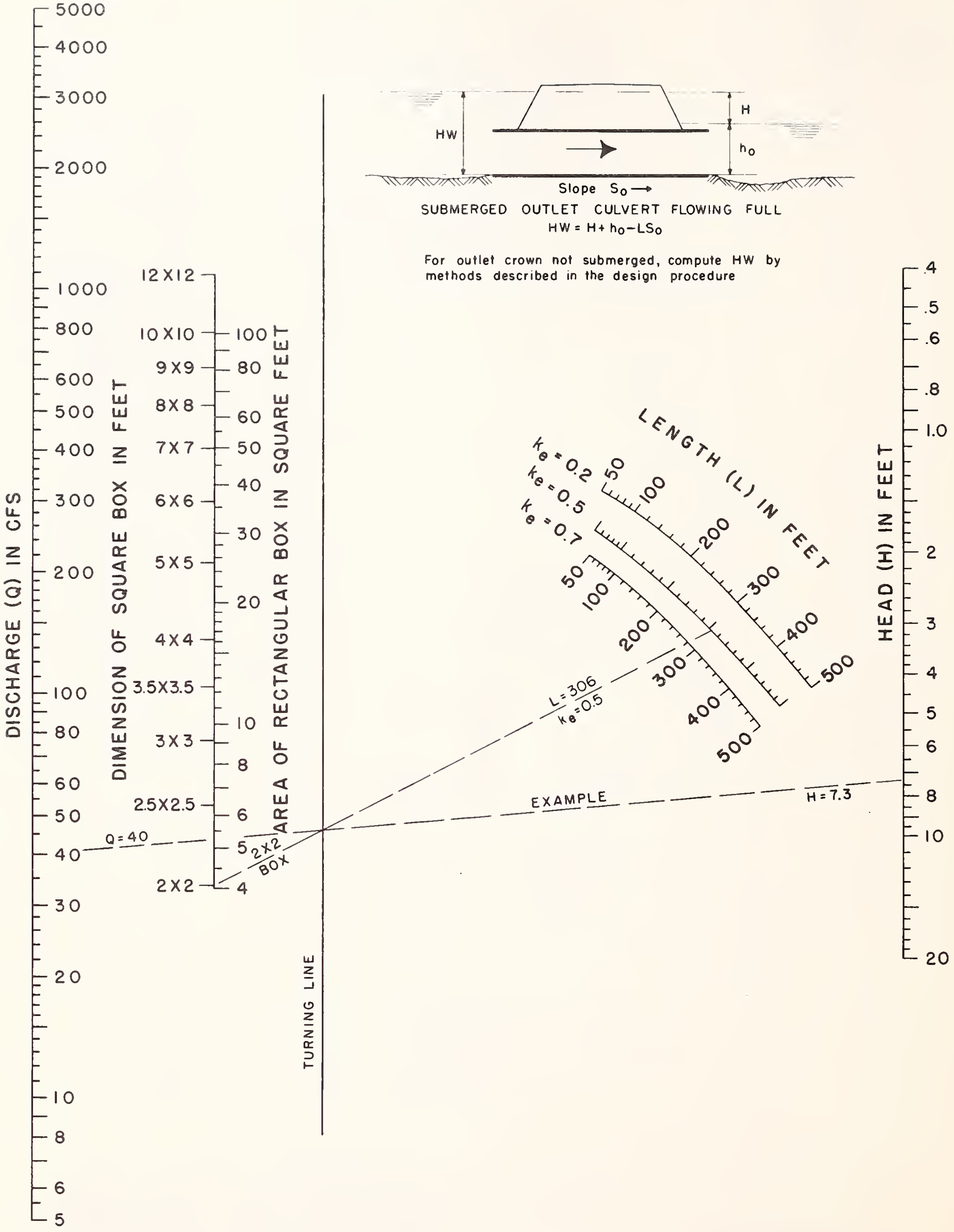
$\frac{b}{D}$	$\frac{a}{D}$	$\frac{c}{D}$	$\frac{d}{D}$	ENTRANCE TYPE
0.042	0.063	0.042	0.083	A
0.083	0.125	0.042	0.125	B



BUREAU OF PUBLIC ROADS
MARCH 1964

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELLED RING INLET CONTROL

CHART 8



SUBMERGED OUTLET CULVERT FLOWING FULL

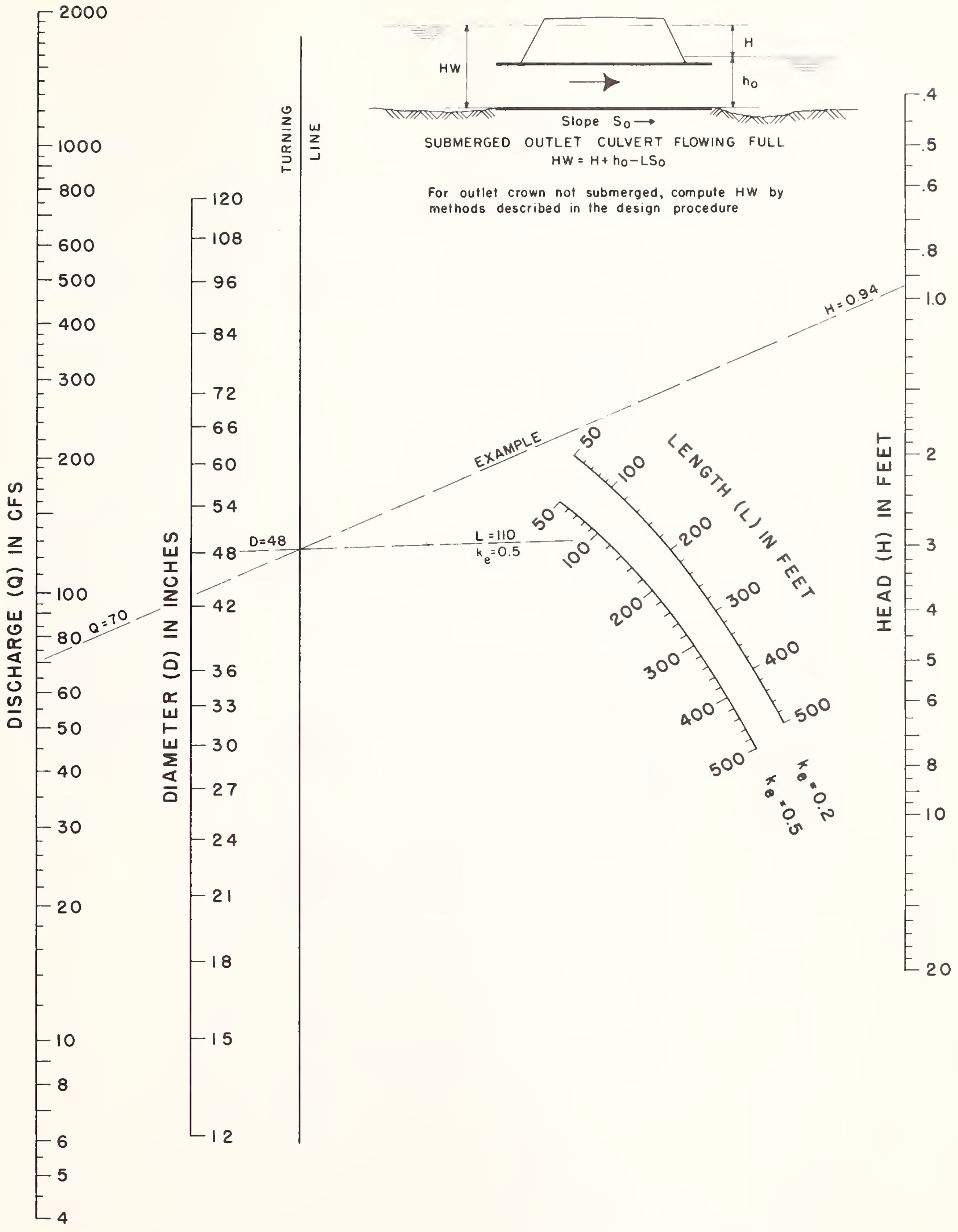
$HW = H + h_o - LS_o$

For outlet crown not submerged, compute HW by methods described in the design procedure

HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 9



SUBMERGED OUTLET CULVERT FLOWING FULL

$HW = H + h_o - LS_o$

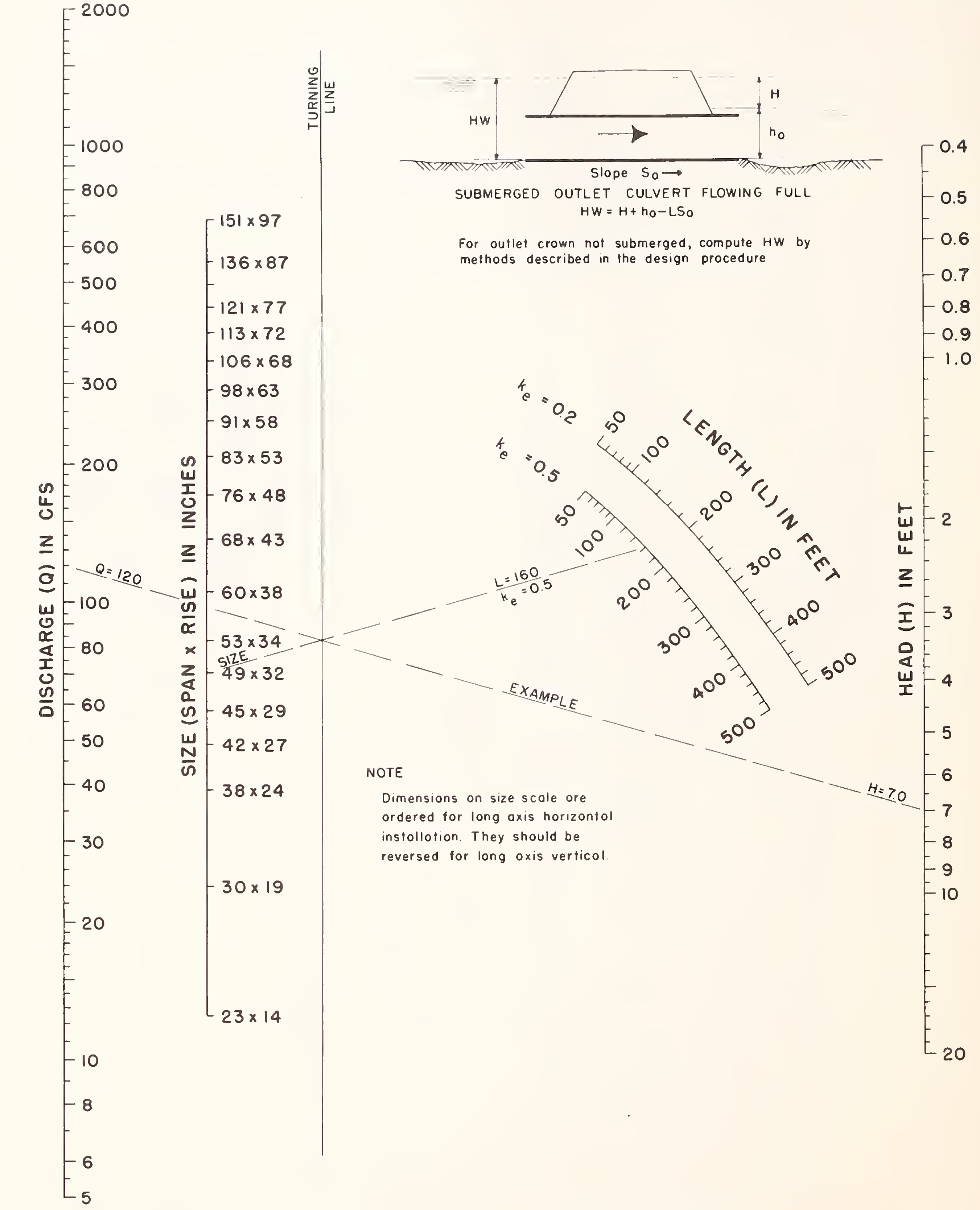
For outlet crown not submerged, compute HW by methods described in the design procedure

HEAD FOR CONCRETE PIPE CULVERTS FLOWING FULL

$n = 0.012$

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 10



For outlet crown not submerged, compute HW by methods described in the design procedure

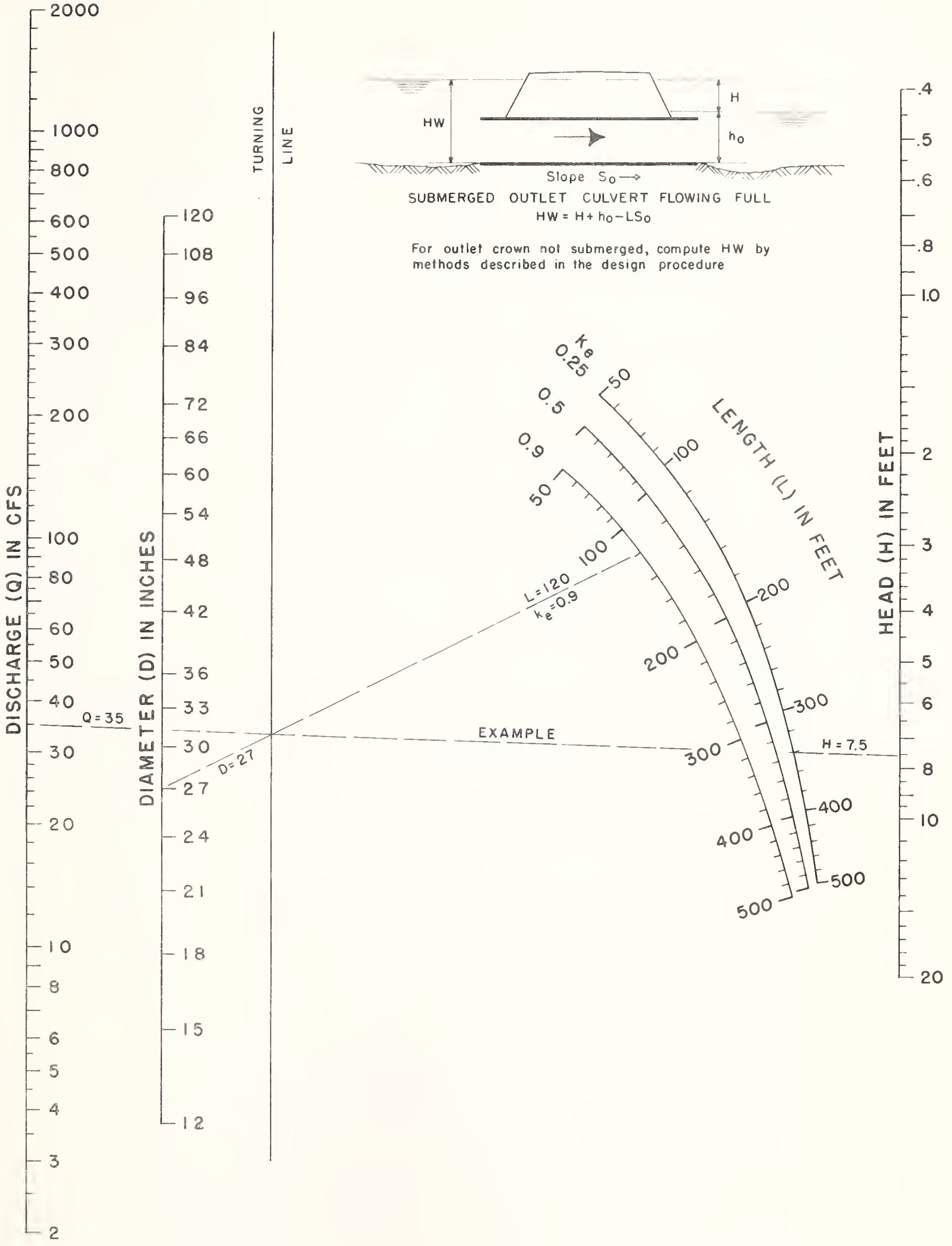
NOTE

Dimensions on size scale are ordered for long axis horizontal installation. They should be reversed for long axis vertical.

HEAD FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL OR VERTICAL
FLOWING FULL
n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

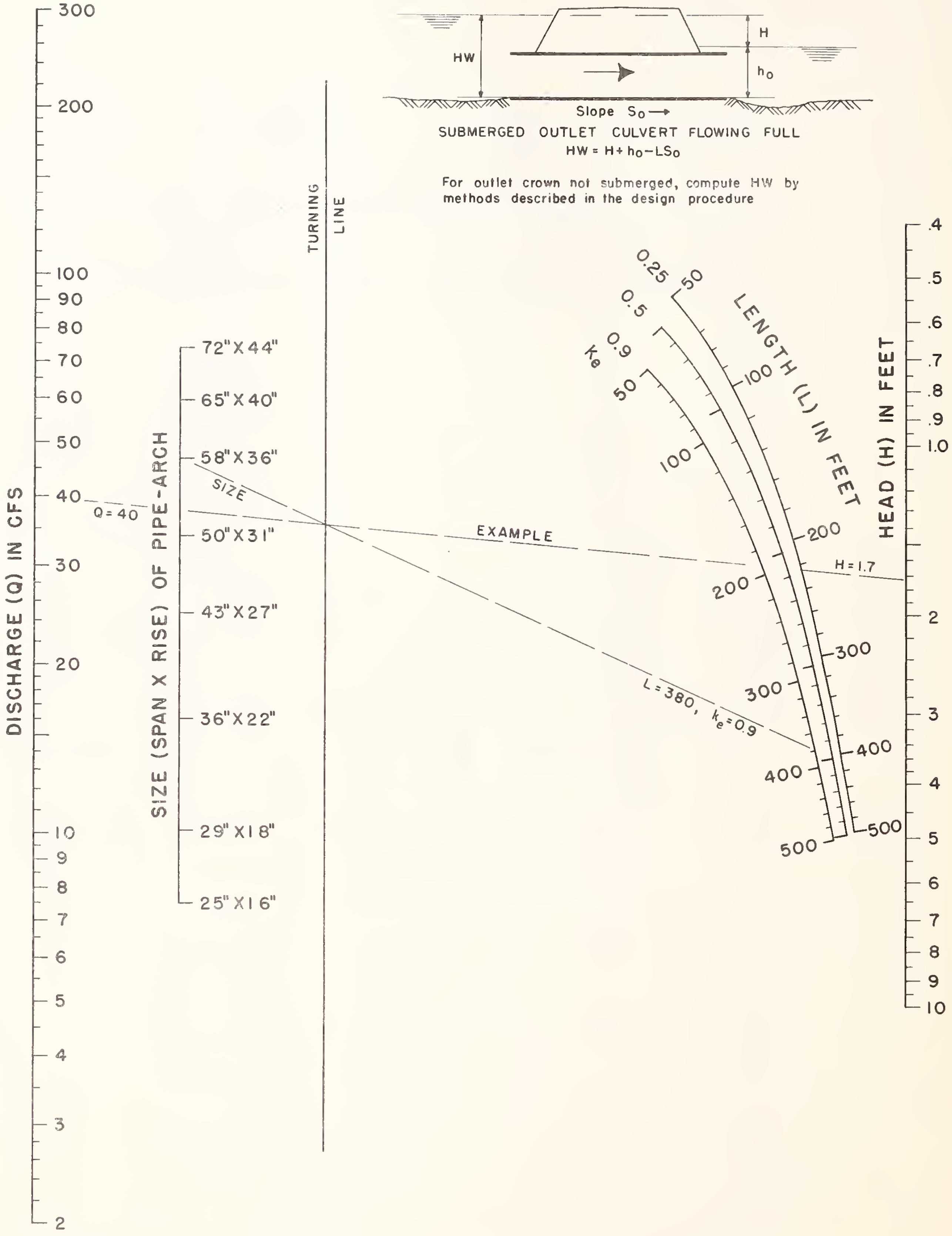
CHART 11



BUREAU OF PUBLIC ROADS JAN. 1963

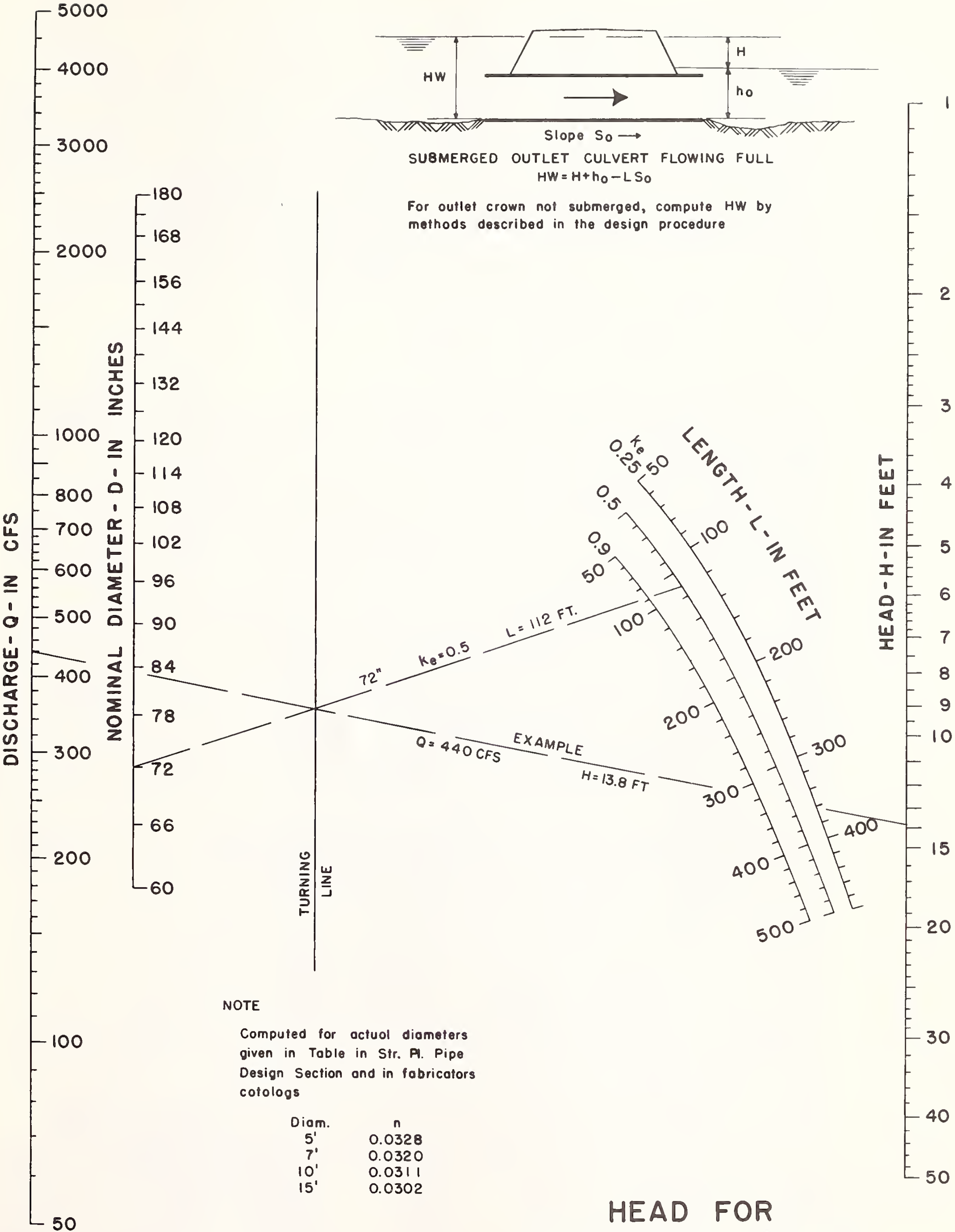
HEAD FOR
STANDARD
C. M. PIPE CULVERTS
FLOWING FULL
n = 0.024

CHART 12



HEAD FOR STANDARD C. M. PIPE-ARCH CULVERTS FLOWING FULL n=0.024

CHART 13



For outlet crown not submerged, compute HW by methods described in the design procedure

NOTE

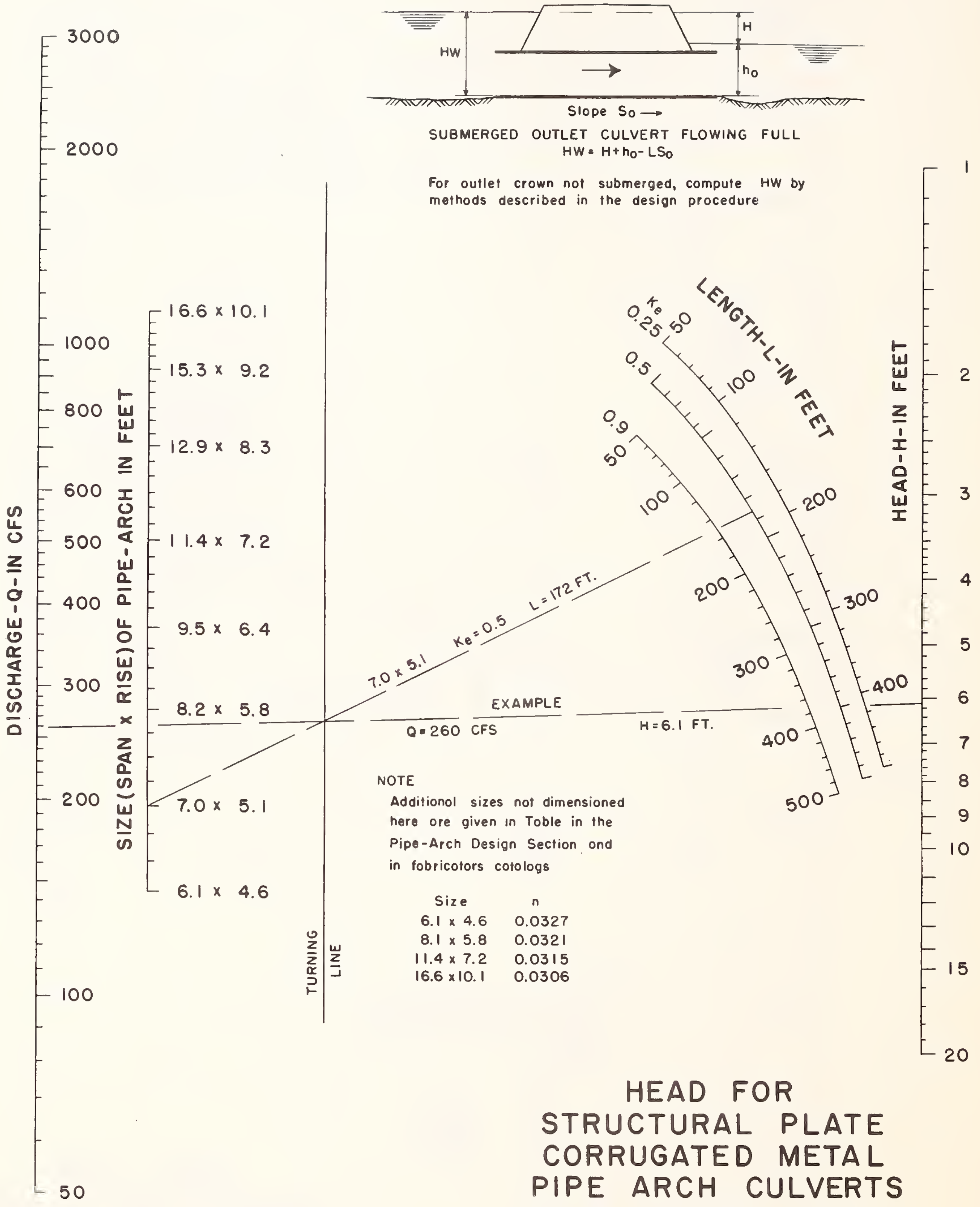
Computed for actual diameters given in Table in Str. Pl. Pipe Design Section and in fabricators catalogs

Diam.	n
5'	0.0328
7'	0.0320
10'	0.0311
15'	0.0302

HEAD FOR STRUCTURAL PLATE CORR. METAL PIPE CULVERTS FLOWING FULL n = 0.0328 TO 0.0302

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 14



NOTE

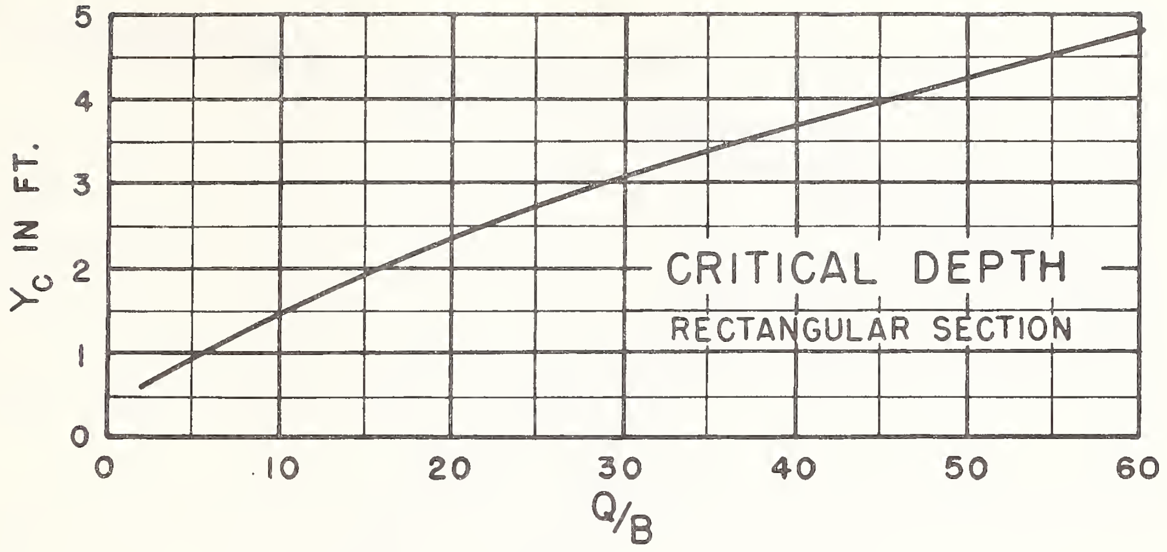
Additional sizes not dimensioned here are given in Table in the Pipe-Arch Design Section and in fabricators catalogs

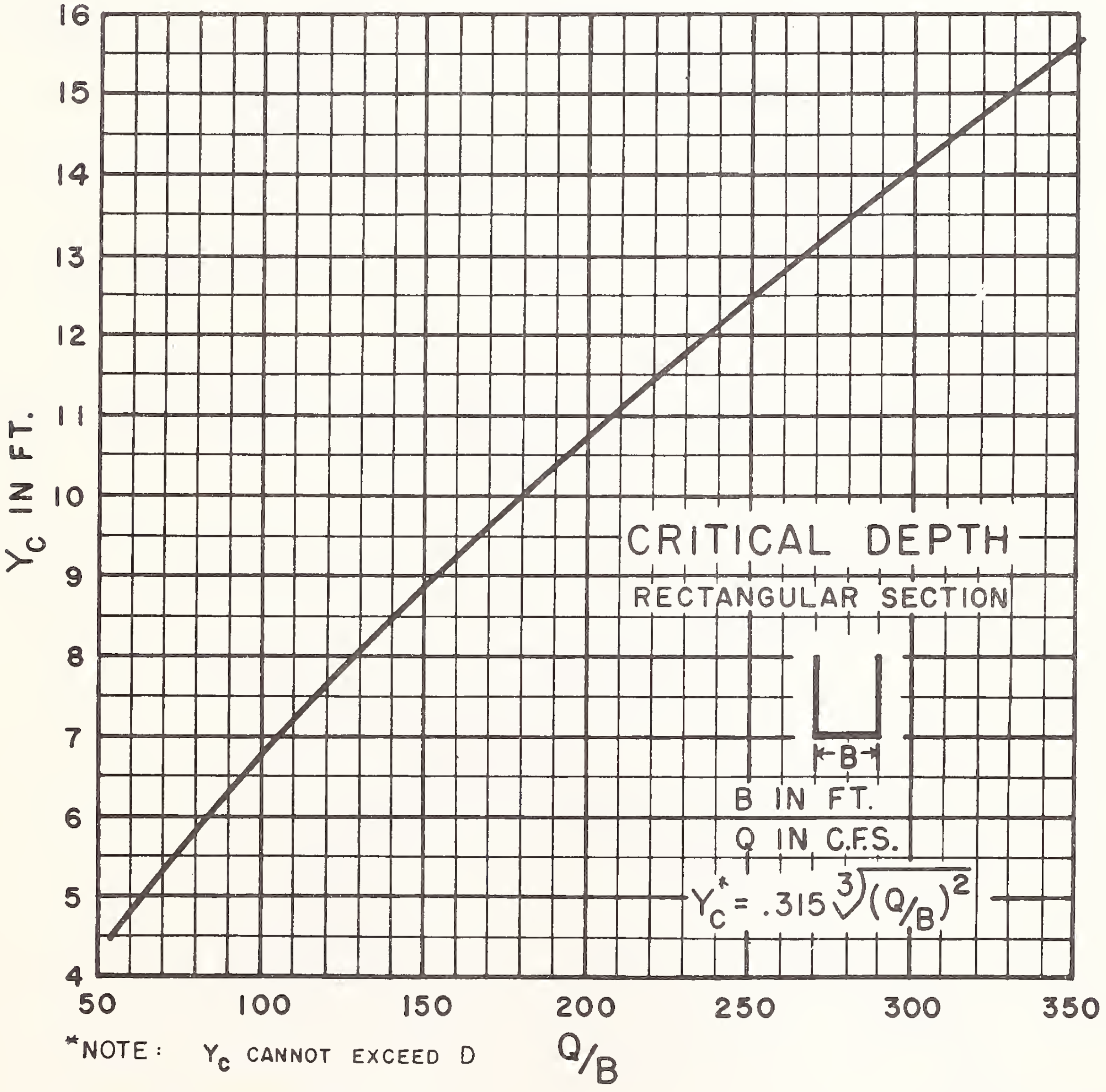
Size	n
6.1 x 4.6	0.0327
8.1 x 5.8	0.0321
11.4 x 7.2	0.0315
16.6 x 10.1	0.0306

HEAD FOR STRUCTURAL PLATE CORRUGATED METAL PIPE ARCH CULVERTS 18 IN. CORNER RADIUS FLOWING FULL n=0.0327 TO 0.0306

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 15

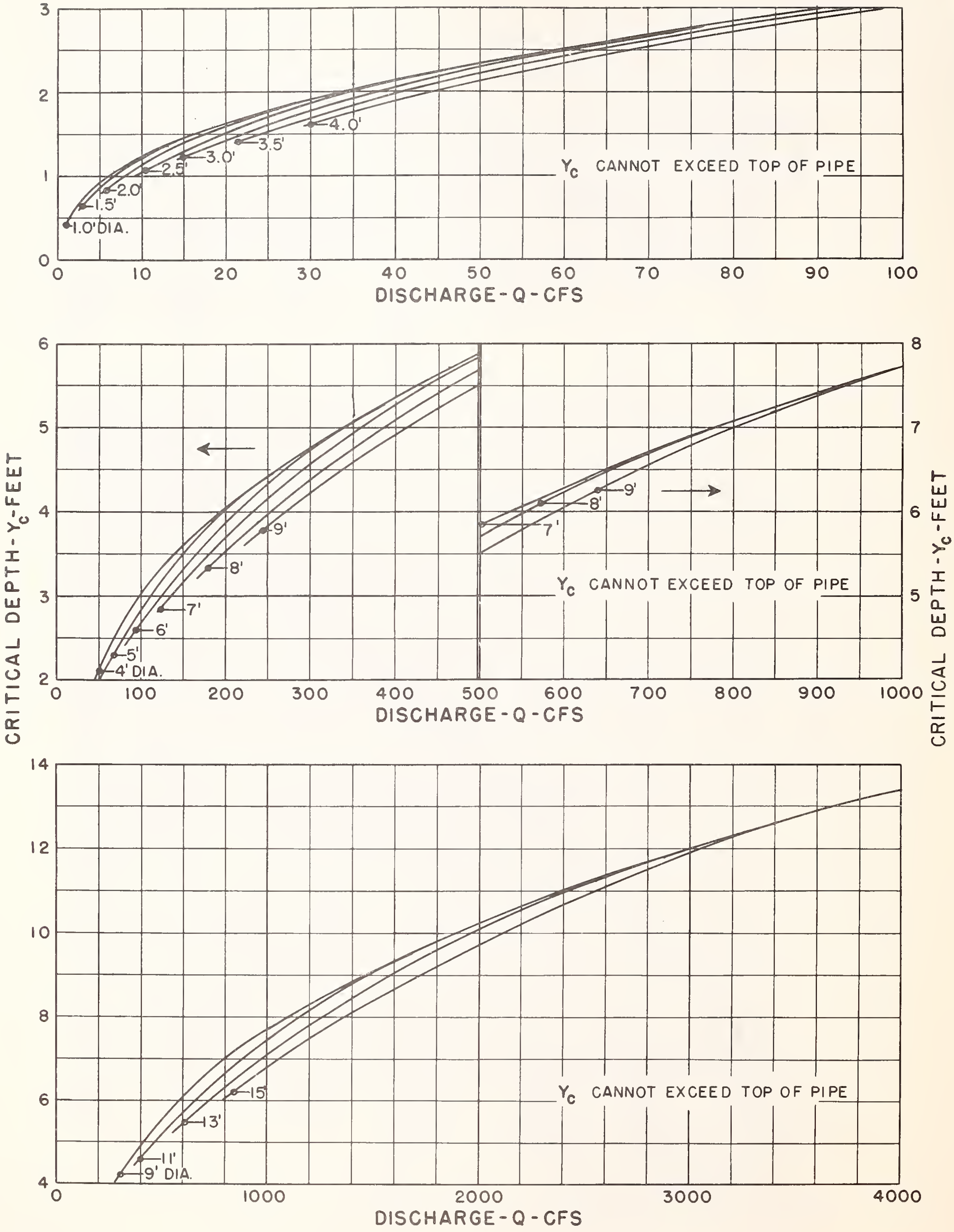




*NOTE: Y_c CANNOT EXCEED D

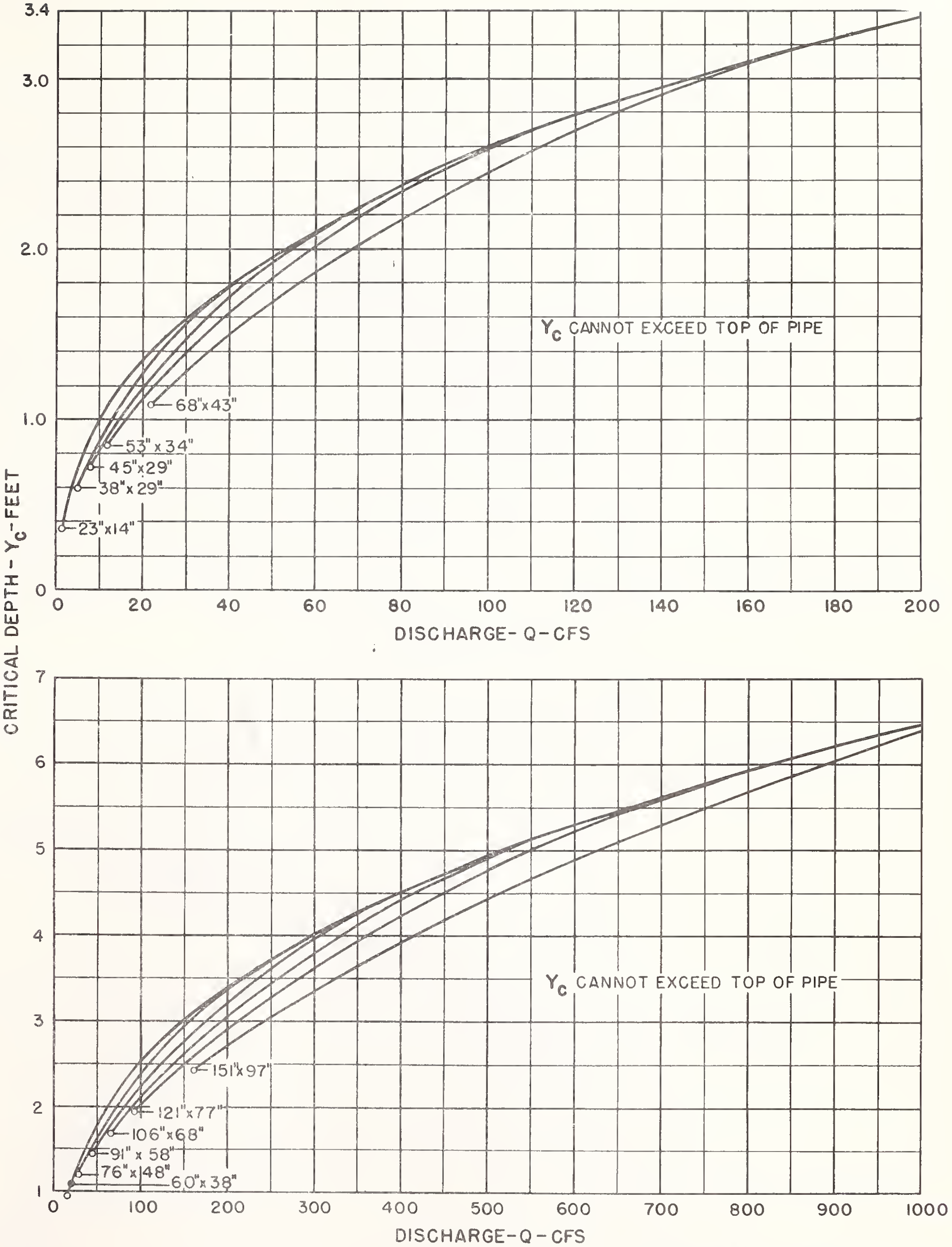
BUREAU OF PUBLIC ROADS JAN. 1963

CHART 16



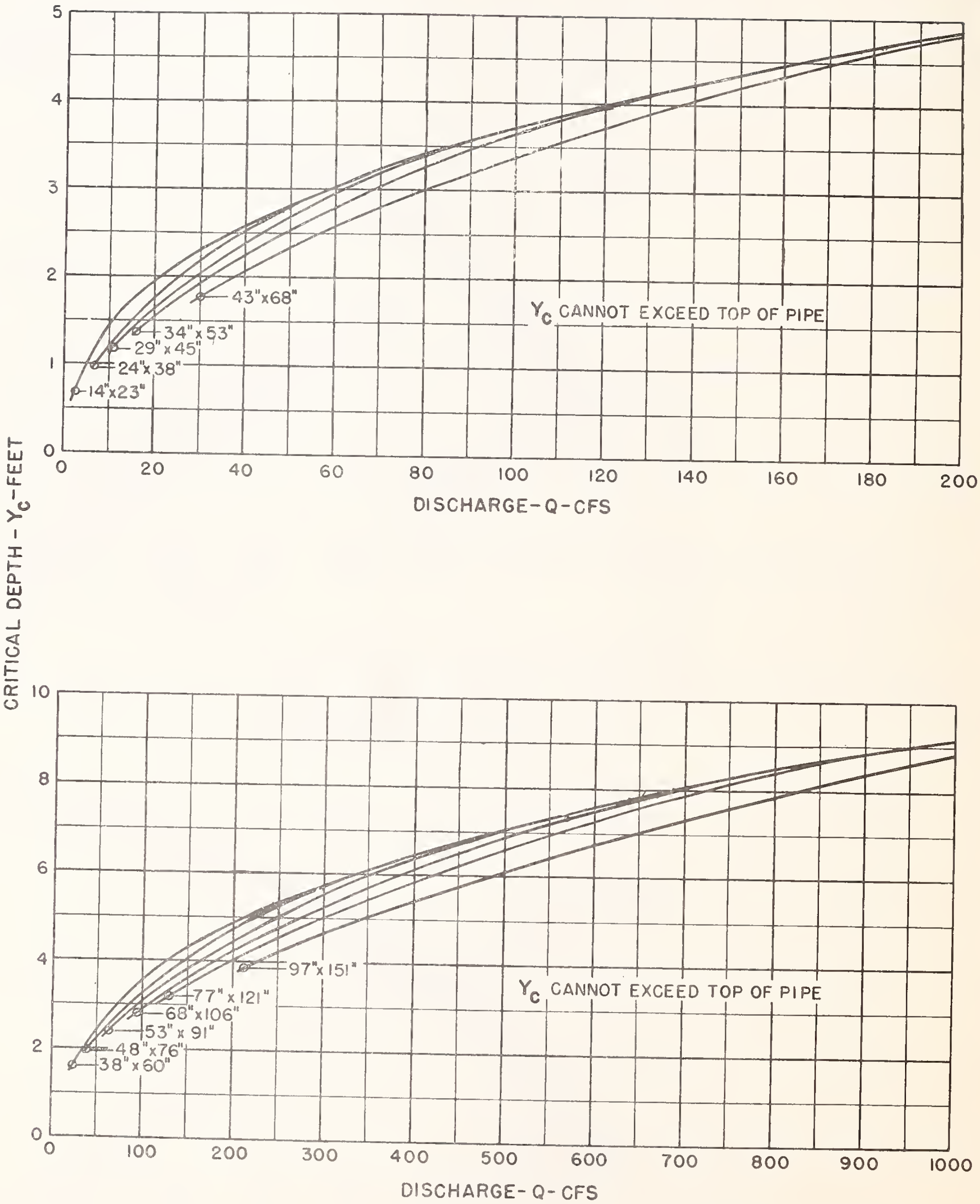
3
2
1
0
1.0'DIA.
1.5'
2.0'
2.5'
3.0'
3.5'
4.0'
Y_c CANNOT EXCEED TOP OF PIPE
0 10 20 30 40 50 60 70 80 90 100
DISCHARGE - Q - CFS
CRITICAL DEPTH - Y_c - FEET
6
5
4
3
2
4' DIA.
5'
6'
7'
8'
9'
7'
8'
9'
Y_c CANNOT EXCEED TOP OF PIPE
8
7
6
5
CRITICAL DEPTH - Y_c - FEET
0 100 200 300 400 500 600 700 800 900 1000
DISCHARGE - Q - CFS
14
12
10
8
6
4
9' DIA.
11'
13'
15'
Y_c CANNOT EXCEED TOP OF PIPE
0 1000 2000 3000 4000
DISCHARGE - Q - CFS

CHART 17



CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS HORIZONTAL

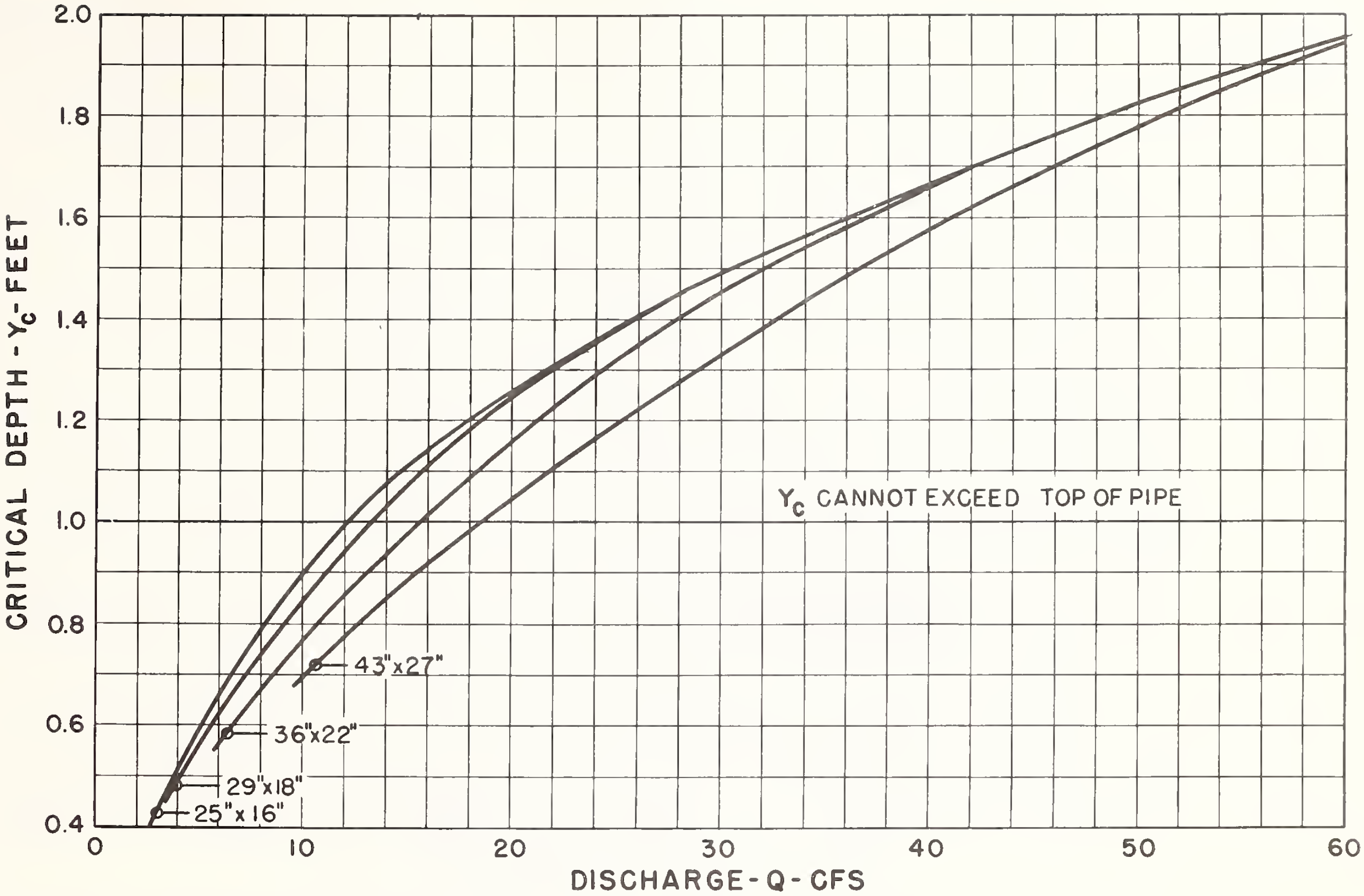
BUREAU OF PUBLIC ROADS JAN. 1964

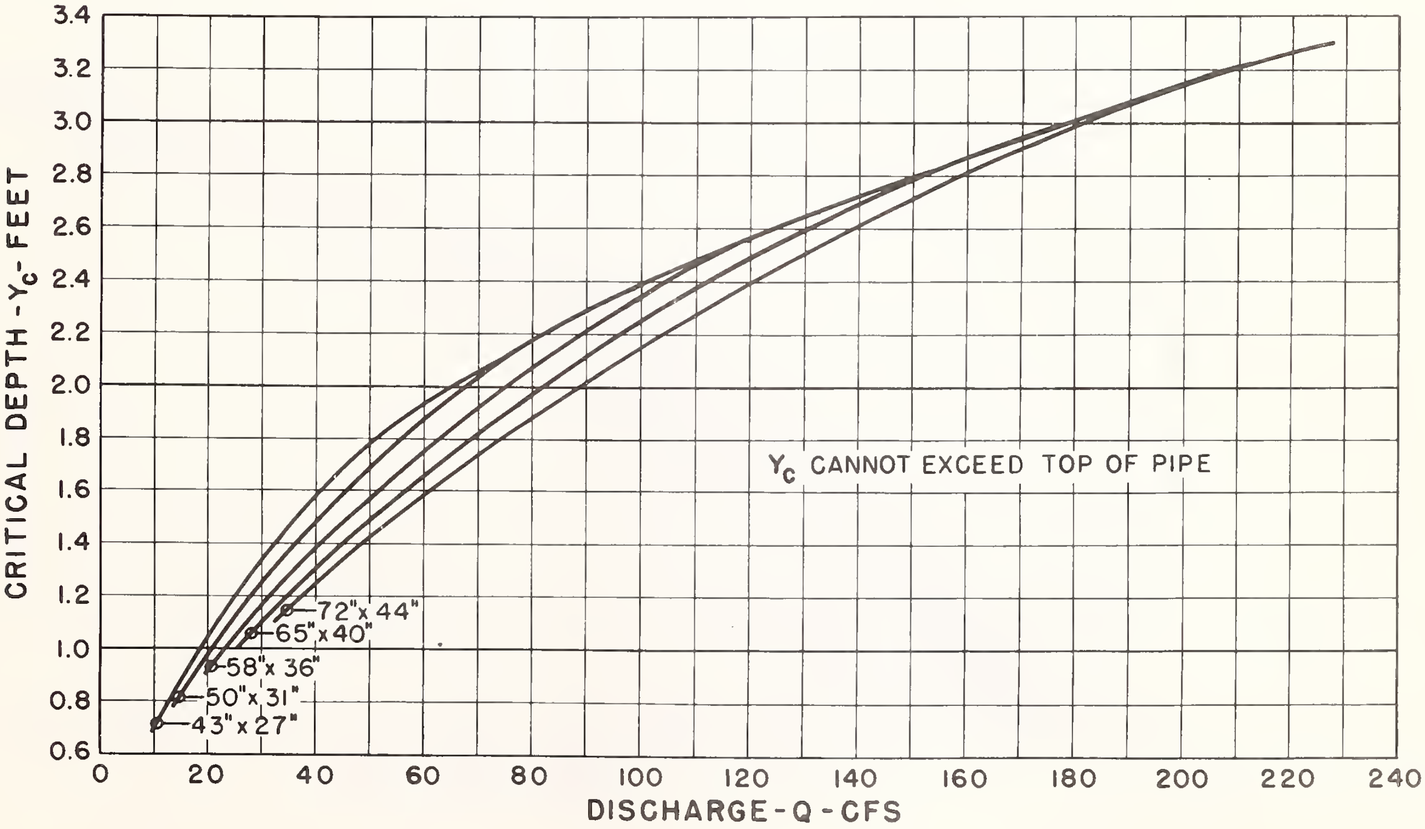


CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS VERTICAL

BUREAU OF PUBLIC ROADS JAN. 1964

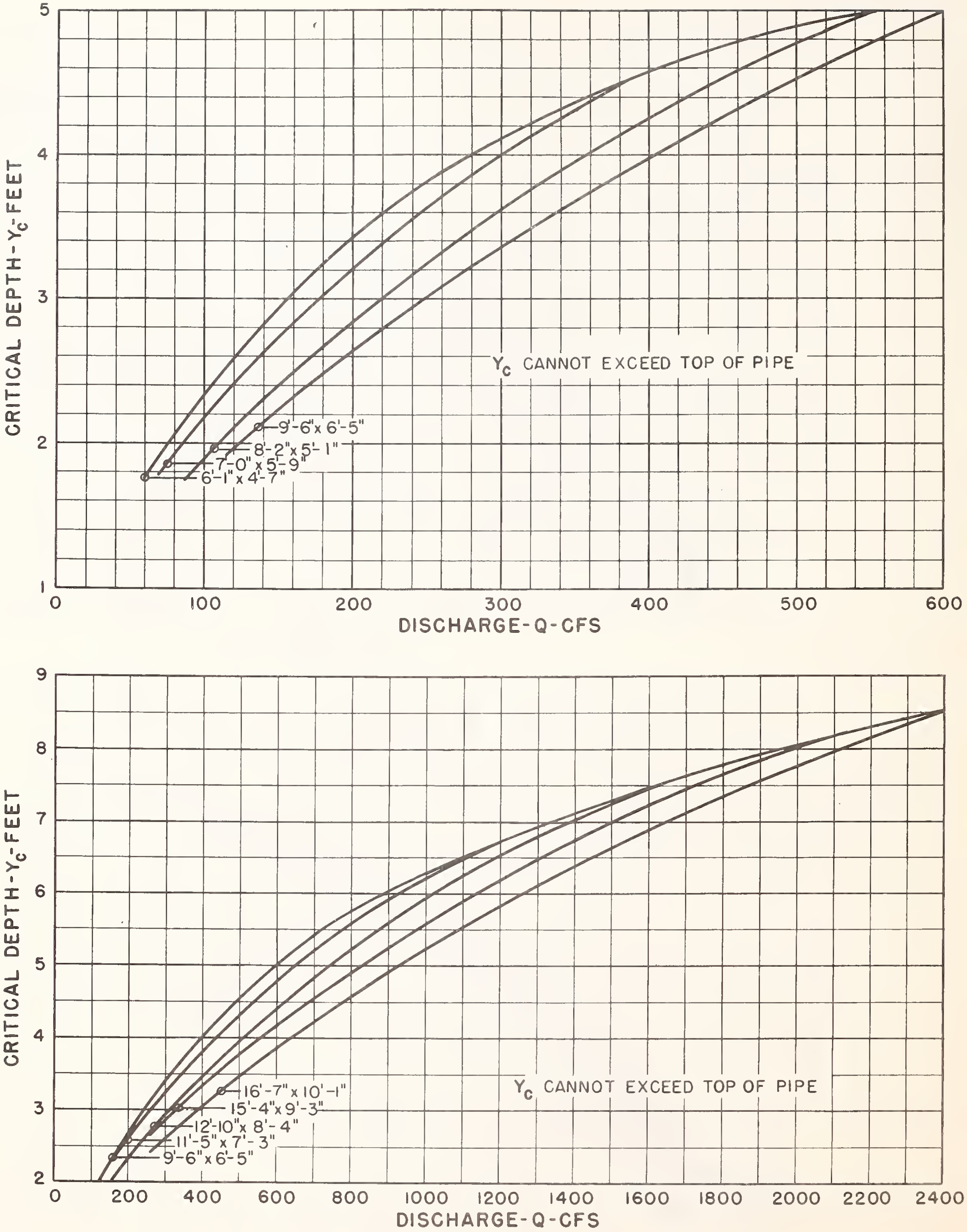
CHART 19





CRITICAL DEPTH
STANDARD C.M. PIPE-ARCH

CHART 20



CRITICAL DEPTH
STRUCTURAL PLATE
C. M. PIPE-ARCH